THE ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

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● *EXPANDING PISTON RINGS*

In internal combustion engines, the employment of conformable oil rings and narrow compression rings will hold down scuffing such as is brought on by the inevitable cylinder distortion. Scuffing is caused by the inability of oil rings to provide a uniform oil film for lubricating compression rings during all operating conditions. If the rings were operating in straight and round cylinders, this would be easy. A properly designed cylinder will remain straight and round, and will provide uniform cooling along the entire stroke length during all operating loads. The only design which could conceivably meet this requirement is a full-floating wet sleeve, which would be free from any thermal or structural deformation. Such a design, however, is too costly for passenger cars or even medium-size lorries. Relatively conformable oil rings have been known for years, but there has hitherto been a prejudice against their use. A recent improvement in the design of conformable oil rings consists in the provision of auxiliary radial pressure. This is done with an inner ring which simultaneously exerts uniform pressure on the ring around its entire circumference, but does not contact the groove bottom. The new equalizer is entirely independent of groove depth, provided sufficient space is available. Such conformable rings are claimed to produce very high reduction in oil consumption.

● *PRODUCTION OF HIGH-PURITY CHROMIUM*

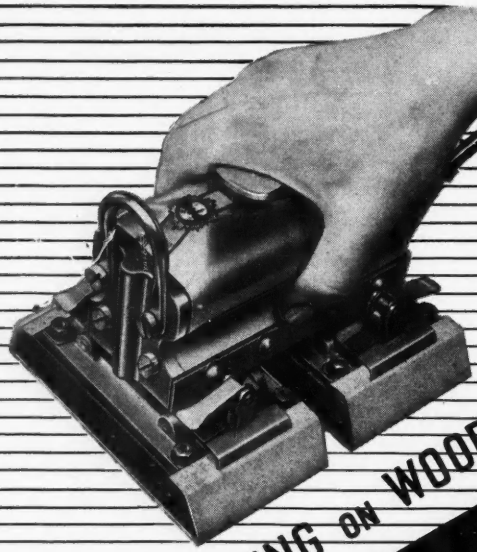
Among various uses of electrolytically produced chromium which are of special importance at the present time are those of non-ferrous chromium alloys for metal-cutting tools, heating elements and electrical appliances, and for parts of jet engines and rockets which are exposed to high operating temperatures. It is, therefore, important to note that according to a recent announcement, chromium can now be produced by means of a novel electrolytic process, which yields this metal at lower cost and with improved purity. Cell feed for this process consists of a concentrated solution of chromium ammonium alum. In order to effect successful electrodeposition at a high current efficiency, the pH value of the solution is carefully controlled. A further requirement is a rapid but non-turbulent flow of the electrolyte over the cathode surface. An interesting feature of the cell assembly is that the anode compartments consist of frames fabricated from sheets of Plexiglas with a Vinyon cloth diaphragm cemented to each side. At a current density of 80 amps per sq ft, and with a cell potential of 4·8 volts, a current efficiency of 60 per cent is obtained, the power consumption being 5·6 kWh per pound of metal produced. At the aforementioned current density and current efficiency, a 73-hour plate will weigh five pounds per sq ft and vary in thickness from 0·15 to 0·2 inch. Temperature control is stated to be important.

● *CIRCULATING PAINT HEATER*

A circulating-type paint heater has been developed, which makes it possible to spray direct from the paint container without the employment of a pressure tank. According to the makers of the device, when paint is heated to a temperature of 180° F prior to spraying, fewer rejects and heavier paint films of better quality are obtained. By heating the paint before spraying, its viscosity is decreased, so that in effect heat is substituted for a thinner. At the same time, reducing the amount of thinner enables the solid contents to be increased accordingly. In consequence, one coat of paint can be employed in place of two, with a resultant saving in time, labour, and materials. Since the paint-heating coils together with the electric cartridge type heating elements are embedded in an aluminium casting, the required uniform heating effect is attained without the employment of water or any other liquid as heat transfer agent. Constant circulation between the heater and the spray gun is provided. The circulating arrangement, which consists of an air motor driving a self-priming explosion-proof fluid pump, can pump directly from any paint container. Both pressure and temperature of the paint are adjustable.

● *WELDING DIFFERENT METAL THICKNESSES*

A newly developed resistance welding control system makes it possible to weld various combinations of material thicknesses on one assembly without any adjustment of welding controls, once the equipment is set for a given operation. Performance of this system rests upon the observation that with the welding machine pressure and current control set at fixed values, steel thicknesses



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within a range of ratios of one to six can be welded merely by varying the welding time, because the determining factor is the welding time and not the number of pieces of steel used in the joint. This means that with a given setting of time, two to five thicknesses can be welded so long as the total joint thickness remains constant. The new device, which in its simplest form is limited to welding three ranges of metal thickness, consists of an indicating head which acts to adjust the welding time control. The head measures the thickness of the metal between the electrodes and responses to three ranges of thickness at a time. It can also be set to measure or to response to any three different combinations as long as the ratio of minimum to maximum joint thickness is one to six or less.

● *ELECTRIC FURNACES WITH OXIDE RESISTORS*

The possibility of constructing electric resistance furnaces capable of operating at very high temperatures in the range from 1,000 to 2,200° C must obviously rest upon the availability of a suitable resistor material for this range. It has long been known that many oxides are electrical conductors, especially at high temperature, but their use as resistor material has hitherto proved impracticable owing to a number of fundamental difficulties. The main objections to the use of oxide resistors in furnaces are the negative temperature coefficient of these materials, starting difficulties, and channeling of the current down one side or the centre of larger resistors, thus limiting the practical side severely; other shortcomings are fragility and poor end connections. Intensive research has, however, been carried out of late, which has now resulted in the successful construction of furnaces of this type, at least on the laboratory scale. The furnaces constructed use stabilized zirconia as heating element. Two such furnaces were built which operate successfully in air at 1600° C, while a hydrogen-atmosphere furnace was found to be capable of operating at 2200° C. Of particular interest is the reported construction and operation at 2200° C in air of an induction furnace with the same material as heating elements, thus entirely overcoming the difficulty of making the end connections to the heating elements.

● *OPTICAL PLATE MARKING-OFF SYSTEM FOR SHIPYARDS*

During the last war, a rapid method for marking-off shipbuilding plates and sections was developed in Germany. This system has now become commercially available and installations have recently been made at Swedish and French shipyards. The optical marking-off process is a method of production, which permits a drawing which is recorded on a 9 × 12 cm-size photographic plate to be projected on the work by optical means. The steel plate can be marked-off directly by following the lines of light forming the projected image of the drawing. The process is based on the knowledge that a one-tenth scale drawing which contains all the details which could normally be transferred to the plate can be executed to such a degree of precision that the traditional mould loft procedure of preparing full-scale drawings on the mould loft floor, and the production and marking-off of templates can be eliminated. The optical marking-off apparatus consists of a projector incorporating a powerful arc lamp. The apparatus is rigidly mounted above the marking-off table, the distance between the equipment and the table depending upon the maximum dimensions of the steel plate, with a maximum of approximately 45 feet. A special lens enlarges the photographic negative 75 to 100 times and projects the image without distortion upon the work surface. The economic advantages of this system are claimed to be remarkable, and similar systems might prove useful in other industries.

● *OXYGEN ANALYZER*

An oxygen analyzer has been introduced which operates on the principle that oxygen is unique among gases in being strongly paramagnetic, whereas other common gases, with few exceptions, are slightly diamagnetic. Oxygen concentrations of only a few parts per million can thus be determined by measuring the magnetic susceptibility of the gas. The apparatus consists of a light dumb-bell shaped element made of two hollow glass spheres which are supported on a fibre made of quartz. The spheres are free to rotate in a non-uniform permanent magnetic field and are subjected to a magnetic force which is proportional to the difference between the volume magnetic susceptibility of the spheres and the gas which they displace. To make the glass test body conductive, it is metal-coated and two electrodes are set near it at fixed electrical potential. A beam of light which is reflected from a mirror attached to the body is divided by a prism to strike two photocells, which are in electrical balance when the test body is in the null position. The light beam divides unequally between the photocells when the test body rotates. This creates an electrical potential in the circuit, which is amplified and used to indicate changes occurring in the oxygen content of the gas sample.

● *ROTARY MERCURY RECTIFIER*

Synchronous mechanical rectifiers of the commutator type suffer from considerable contact wastage. In order to minimise such wear, apparatus has been designed in which one or both contacting parts consist of mercury. Thus, for instance, the rectifier invented by Prof. Hartmann employs an oscillating jet of mercury which is synchronously driven by an electro-

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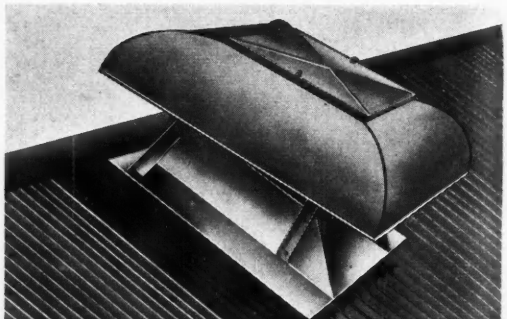

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magnetic field. A recently evolved design is based upon the use of mercury-type contactors in which the mercury is contained in a small sealed glass container, contact between the terminals being made or broken by appropriate tilting of the container. To tilt such a container at synchronous speed requires that the mercury contents should be able to oscillate at the required high speed, so as to make and break contact synchronously. Under ordinary conditions, the rate of oscillations would, however, be unobtainable, since the natural frequency of the mass of mercury present is much too low. The solution to the problem has been found in a device in which the glass containers revolve at high peripheral speed around a rotating shaft, thus subjecting the mercury contents to a strong centrifugal force. This produces the required high natural frequency of oscillation. Tilting of the rotating containers for making and breaking contact in synchronism is accomplished by the action of stationary cams, eccentrics, or similar mechanical devices.

● *THERMOGRAPHY*

The recently coined term " thermography " applies to the lately developed technique of visually ascertaining and obtaining a permanent photographic record of heat distribution in solid bodies and in fluids. Although this technique is still in its initial stages, it has already become obvious that it may constitute a highly useful tool in establishing heat flux fields in cases which are difficult or impossible to assess by ordinary methods. Details of two thermographic methods have recently been published. In the one of these, use is made of the fact that certain phosphors are temperature-sensitive to such a degree that small localised increases in temperature in a thin phosphor layer reveal themselves as relatively dark areas when the layer is illuminated by ultra-violet light. In the apparatus used, an image of the body is produced on a phosphor-covered screen by means of a concave mirror, the screen also being exposed to ultra-violet radiation. The image formed on the screen is photographed by means of a camera, the lens of which is provided with a filter to absorb scattered ultra-violet light. In the other method, the image is produced by means of a rock-salt lens on a thin layer of silver-mercury-iodide or copper-mercury-iodide and is photographed. Practical developments of these methods will be awaited with considerable interest.

● *UNDERWATER CAMERA*

A completely mobile underwater motion-picture camera, independent of air supply, with electric cables leading to the surface, has been developed by the U.S. Navy. The camera as well as techniques for making the diver-photographer entirely independent of surface assistance were developed for the U.S. Navy's programme, now under way, to provide a series of training films for deep-sea divers. The submarine motion-picture camera is designed so that it can be completely operated from the outside, with external controls for the lens diaphragm, focus, and start-stop switch. It has detachable wings and a vertical rudder which aid in transporting and stabilizing the camera under water. The camera wings act as a planing surface, so that the diver-photographer can sight on his target through the viewfinder, kick his flippered feet, and guide himself by tilting and banking the camera similar to a plane in air. The underwater photographer is equipped with a self-contained automatic compressed-air diving unit, a face mask, and swim fins on his feet. Equipped in this fashion, the photographer is able to swim with the camera in any direction or to any depth down to approximately 200 ft. The camera weighs about 107 lb in air, but can be adjusted to have either positive, negative, or neutral buoyancy under water. In time of danger, it can also be released to rise freely to the surface.

● *NOVEL SHIP'S PROPELLER*

In order to increase the manoeuvrability of vessels for service in narrow waters and harbours and, in particular, for ferry service, several types of unorthodox propulsion plants have been proposed and developed in recent years. In all these types, the propeller is capable of exerting a considerable steering action supplementary to that of the rudder proper, and in some designs the rudder can be dispensed with altogether. The latest—yet untried—suggestion consists in providing two pairs of auxiliary propellers fore and aft respectively, these propellers being retractable into housings in a manner similar to that employed in fin stabilizing devices. In order to circumvent the need for mechanical drives, it is proposed to make these propellers of the single-reaction turbine type, that is, employing the same principle as is used in lawn sprinklers of the rotating type. Such a propeller would receive pressure water through a hollow shaft and have ejection nozzles at the blade tips. The reaction force thus created would then be used to drive the propeller blades. Astern operation could be easily obtained by swinging the propeller round along the axis of the pressure water supply tube.

● *NEW SURFACE-HARDENING PROCESS*

The great activity prevailing at the present time in the development of methods for producing wear-resisting surfaces on steel is exemplified by two proposals, information on which has just become available. The first of these concerns the production of surface layers of very great hardness, such as are required for the bits of

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cutting tools, coal drills, sand blast nozzles, etc., to be subjected to hard wear. The surface layer employed comprises carbides of tungsten, titanium, silicon, or boron. The process consists in heating an oxide of these elements together with lamp black in a furnace to a temperature of 500 to 1,000° C in the presence of chlorine or bromine. The resultant gases are purified and then mixed with hydrogen, and the mixture passed over the material to be treated, which is heated in a separate furnace to 1200 to 1500° C. It is interesting to note that the production of hard coatings by this method on graphite is also envisaged. In the second process, the steel part to be treated is first subjected to a diffusion treatment in a salt bath containing, for instance, anhydrous sodium tungstate in an atmosphere of hydrogen. This process produces a tungsten surface content of 10 to 15 per cent. Titanium, vanadium, columbium, tantalum, chromium, or molybdenum layers can be produced in a similar way. The part thus pre-treated is then carburised in a suitable gas atmosphere, which, by diffusion, produces within the original layer a hard intermetallic phase.

● *STERILISING BY CATHODE RAYS*

It has been discovered that cathode rays possess sterilising properties, and experiments to sterilise bread, meat and other foods have shown that as a result of cathode-ray treatment, these foodstuffs could be preserved for periods as long as one year without refrigeration. It is, therefore, established beyond doubt that these rays are capable of destroying moulds and other organisms which normally cause such foods to deteriorate. While it is too early to predict specific commercial applications, the employment of this sterilising process would appear to be particularly attractive with regard to materials which must not be exposed to the heat required by usual sterilising methods. It need hardly be stressed that once a material has been sterilised by the new method, it must be kept away from the open air so as to prevent the re-entry of the harmful micro-organisms. Inherent limitations of cathode-ray sterilisation are that it may cause changes in colour, taste and odour of the material treated; chemical changes may also be caused. The sterilising properties of cathode rays were discovered with the use of a million-volt X-ray unit energising a special accelerating tube provided with a stainless-steel window through which the cathode rays pass into open air.

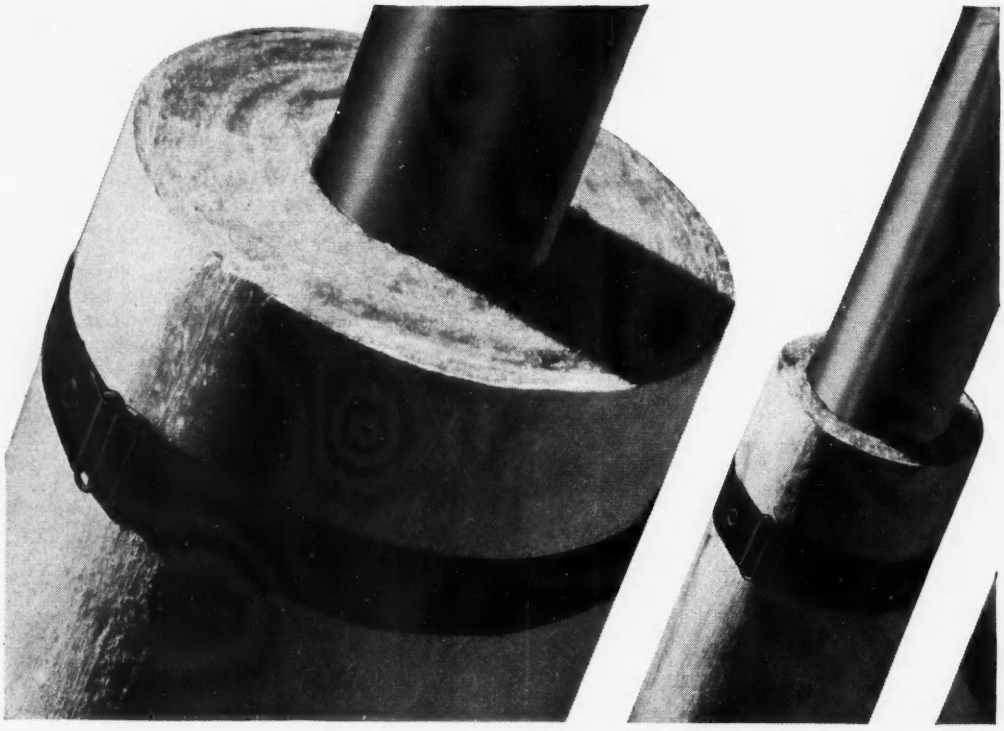
● *CABLE-PULLEY FRICTION*

In the case of motion transmission, such as is experienced in control systems and hoisting, haulage and transporting services, cable-pulley systems are employed for transferring a force by means of the cable. The pulleys are used merely for the purpose of directing this force from the point of application to the point of action. The presence of large frictional losses in such systems must necessarily have a detrimental effect upon the operation and life of the system and should, therefore, be avoided. This problem is especially important in control systems such as are used in aircraft, where limitations of equipment and design are present, where quick and dependable action is of utmost importance, and where manual overcoming of the friction of the system may result in undue exhaustion of the pilot. In other applications, even though the problem may be of lesser importance, reduction of the friction of the system will produce higher efficiency and more satisfactory operation. Basic information on the relative importance of the factors involved has now become available through the publication of exhaustive research data. The conclusions arrived at are that the friction in cable-pulley systems increases with increasing cable tension, angle of cable bend, diameter of the cable, and with decreasing pulley diameter. Empirical equations for determining the total dynamic friction and for the critical angle of cable-bending friction have also been established.

● *TEMPERATURE MEASUREMENT AND CONTROL OF HOT GASES*

The measurement of the gas temperature prevailing in the combustion chambers of gas turbines is known to present formidable difficulties. First of all, it is, of course, difficult to arrive at a definition of gas temperature, since this is by no means uniform throughout the combustion chamber. Local measurement may, therefore, prove quite misleading, especially as it depends upon the combustion and chemical reactions prevailing, which may or may not be complete, according to the load carried by the turbine. In order to arrive at a solution which affords both sufficiently accurate and relatively simple measurement of the temperature of the gas stream, methods have been evolved in which the temperature of the gas stream is derived indirectly by utilising the thermodynamic characteristics of gas streams expanding through orifices. These methods are claimed to yield average combustion chamber temperatures with an error of within 2 per cent. The actual procedure consists of tapping-off a small flow of gas and then examining its expansion characteristics, which can be carried out in several ways. It goes without saying that methods of this nature need not be confined to temperature measurement, but can be incorporated in control gear for adjusting fuel and combustion air supply.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.



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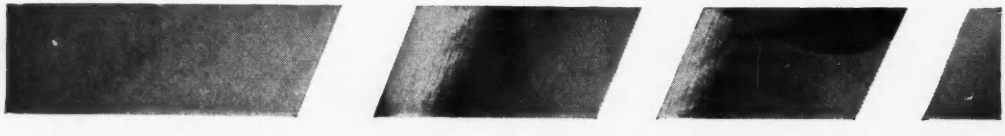

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Cybernetics — or the Science of Governing

CYBERNETICS (from the Greek $\chi\upsilon\beta\varepsilon\rho\nu\acute{\eta}\tau\eta\varsigma$ = steersman) is a very new branch of science and, as often happens nowadays, cannot be classified under any of the traditional subjects. It deals with problems of communication and control, both in animals (human or otherwise) and in machines. Although its technique is mainly mathematical, it is related to physics, chemistry, engineering, biology, physiology, psychopathology, the social sciences and a host of other fields.

The interest in such problems lies first of all in the fact that man is primarily a communicating animal, his civilisation (such as it is) rests first and foremost on communication and resultant co-operation, and what cohesion there is in a social group is due precisely to the links of intercommunication between its members. Furthermore, the functioning of the animal organism itself is wholly dependent on the ability of the brain to communicate with, and thus control, the rest of the body. There is no bodily activity, voluntary or reflex, which is not directed by that enormous bureaucracy of 15 thousand million brain cells, exchanging coded messages and linked with the body by ten million incoming telegraph wires, the nerves, which transmit electrical messages at the rate of about 200 mph.

Another reason why the principles of control and communication are of special interest to us today is the fact that the 20th century may be fairly accurately described as the era of communication engineering, just as the 19th century was the era of power engineering The telephone, wireless, television, radar, traffic lights, self-regulating mechanisms (governors, thermostats, guided missiles, automatic computing machines, etc.), increasing centralisation of government, are just as characteristic of our age as were the steam-engine and power-plant of the last century. It would not be too far-fetched to say that, for instance, the Battle of Britain was won by the timely development of the radar (i.e., communication) system.

This way of looking at things may be very interesting, but as yet hardly constitutes a branch of science. However, the very process of seeing the various relations of our world from a new angle does in fact provide the basis for a new science. What remains to be done is to manufacture a new set of abstractions from this new point of view, define them rigorously (if possible, by mathematics, our most powerful tool of abstraction), show that the use of these new abstractions brings together a class of hitherto unrelated phenomena, or makes existing relations simpler and more evident, and finally, manipulate them to enable us to make valid predictions about the phenomena. This is the method of all sciences (even though the process is usually far less systematic), and the method of cybernetics as well. Observe that the idea of communication enters here too : by abstracting concepts from observed phenomena, we put them into words, i.e., make them into tools of communication. The words themselves, by the powerful associations they evoke, serve not only to pool our observations and ideas, but will very often suggest new relations worth exploring.

Some of the most fundamental concepts (or abstractions) of cybernetics are : decision, information, noise, feedback and oscillation, as well as some purely mathematical concepts such as groups, transformations, invariants, etc. Since, however, we do not wish to become involved in mathematics, our definitions must necessarily be merely descriptive. To begin with, a decision is a single choice between two equally probable and mutually exclusive alternatives, one of which is bound to happen : e.g., heads or tails. It can be shown by mathematical logic that any decision, however complex, can be broken down into a series of choices between alternatives. Such a simple choice is also the simplest form and unit of information. To measure the amount of information given by, e.g., a measurement of a quantity to a certain accuracy, we must first express the significant figures of our measurement as a binary number (i.e., using only the digits 0 and 1 instead of all the ten, so that in this notation 0 = 0, 1 = 1, 2 = 10, 3 = 11, 4 = 100, 5 = 101 and so on). Each digit can then only be 0 or 1, i.e., each represents a simple decision. The amount of information given is then broadly the number of decisions made in describing it, so that a perfectly precise measurement gives infinite information. Information, of course, can take many other forms, like Morse signals, or sounds transmitted by telecommunication devices (of which our voice is one), or electrical impulses along our nerve-fibres.

The concept of noise is already familiar to telecommunication engineers. It is, as its name suggests, a background to any communication, inherent in the nature of the apparatus of transmission, which sets a limit to the fineness of detail of the information carried. A message without noise would again contain infinite information. Another term borrowed from the engineer is feed-back. A simple example of feed-back is a thermostatic control-system, the principle involved being that part of the "output" (in this case heat) of the apparatus to be controlled is fed back into it by acting on a control switch. This switch is so designed that when the temperature is greater than the required amount, it switches off the source of heat, while if the temperature is less, it turns on the apparatus more. Other examples of a feed-back mechanism are steam-engine governors, automatic pilots, guided rockets, etc.

At this stage we might consider a few applications of these ideas to various problems. To physicists and chemists it will be of interest that information can be identified with *negative entropy* and has all the properties associated with entropy. This can be shown mathematically, but may also be intuitively seen by considering that information implies an *organised* succession of signals, while entropy is a measure of *disorganisation*. Many interesting consequences and some fascinating speculations follow from this identification, such as a possible understanding of enzymes and even of whole living organisms in terms of "metastable states" feeding on negative entropy. However, there is only space here to hint at these ideas.

The binary principle, on which our concept of information is based (and on which most modern computing machines are designed, about which more will be said later), is very remarkably manifested in the operation of a nerve cell. In its normal mode of action

it is either at rest, or it " fires," almost independently of the nature and intensity of the stimulus. The joints between the nerve cells are called *synapses*, and it is the state of the synapse (broadly speaking), which determines whether an outgoing nerve-fibre will fire or not. The synapses again have a close analogy in the so-called " gates " of an electronic computing machine.

We may next consider typical feed-back phenomena in the living organism. Suppose we want to pick up an object. We have no individual control over the appropriate muscles; all we do is to *will* the complete action. Our motions will then be controlled by the amount by which the object is not yet picked up, i.e., the difference between the actual and the required output is fed back through the control system eye-nerve-brain-output nerve, though other senses, such as the kinaesthetic (muscular sensations), also feed back information.

Again, there are well-known nervous diseases which exhibit symptoms of what might be described as deficient or excessive feed-back, both conditions being very familiar to designers of servo-mechanisms and have been thoroughly analysed. For instance, the condition known as " hunting " to the engineer is completely analogous to the disease known as " purpose tremor."

Other, more complicated, types of feed-back are firing controls exercised by radar controls of an anti-aircraft gun or by the brain of a huntsman. These are termed anticipatory feed-backs, as the amount fed back is the difference between the position of the gun and the anticipated position of the target.

A last and very important example of the feed-back principle is *homeostasis*, that is, the mechanism whereby animals stay within the limits of body temperature, blood pressure and composition, heart-beat rate, etc., which are essential for the continuation of life. These limits, especially in man, are in some cases extremely narrow, e.g., a variation of half a centigrade in the body temperature is already a sign of illness.

It should be noted that the essential principle of operation of the feed-back mechanism is the minimisation of the difference between two quantities. This problem is well known to mathematicians and has been studied under the name of " calculus of variations."

Let us now turn to the famous and much disputed analogy of the computing machine and the human brain. This is often misinterpreted as meaning that the machine possesses *all* the essential attributes of the brain. This is obviously absurd, since it could then, for example, design itself, but none the less, the analogy is very illuminating and suggestive if we recognise its limitations.

Although the design of large electronic computing machines cannot be considered here, we have already compared nerve-cells with the binary units (usually two valves arranged in a flip-flop circuit) of the machine, and have also found an analogy of nerve-synapses in the " gates " of the computer. A third and even more suggestive comparison is that between memory in the nervous system and the " memory " (so-called) of the machine. The function of memory is essentially the preservation of past results or experiences for use later on. It is convenient to distinguish between " short-term " memory and " long-term " memory or learning. Short-term memory in the machine is usually a circular process, that is, a set of signals (representing the stored data in the form of a binary code) travels round a closed circuit. This circuit, which may have many practical forms, can be " tapped " at appropriate times to deliver the particular data required, and may be completely cleared when the stored data are no longer required. Now it seems fairly certain that the human memory is also essentially a set of circular processes along a very large (but not inexhaustible) number of paths of nerve-cells in our brain (this is instinctively recognised by the saying : " it keeps going round in my head "). Brain-surgery, as performed on animals at any rate, shows that the removal of circular " memory lobes " results in loss of memory.

The formation of long-term or permanent memories may then be explained in terms of several " exposures " (or an exceptionally intense stimulus) causing a permanent rearrangement of brain-cell patterns. These structural alterations influence the whole future behaviour of the brain, which functions mainly by comparing new stimuli with already existing patterns. In the machine, learning can similarly consist of causing any message going into storage to change in a permanent way, for instance, the grid-bias of a number of valves, so that, as a result, the machine will have a slightly different response to incoming impulses.

It should be remarked at this stage that the correct analogy is that between the brain and a *single run* on a computing machine, as the brain does not ever " clear " its memory completely during its existence as the machine does after finishing its task.

The computing machine is not the only one which imitates certain functions of the brain. A chess-playing machine has recently been designed in the U.S.A. (which, incidentally, could probably defeat its own designer !). Other machines could be constructed so as to be capable of designing filters, relay and switching systems, handling the routing of telephone calls based on individual circumstances, performing symbolic operations, making logical deductions, translating from one language to another, making strategic decisions, orchestrating a melody, acting as cricket umpires and many others. The study of such machines is bound to have important repercussions in the field of logic as well.

Another, closely related, field is the replacement of lost faculties by mechanical means. Perhaps the most striking achievement here has been the design of an apparatus capable of converting the shapes of printed letters into sound signals, used as a reading device for the blind. This involves some means of recognition of the essential character of each letter, irrespective of variations in size and design. When the diagram of this apparatus was shown to an eminent brain surgeon, it immediately suggested to him part of the visual cortex of the brain ! The solution of this problem has far-reaching psychological and even philosophical implications, because it suggests an answer to the question " How do we recognise " universals," e.g., a square as a square, whatever its size, distance and orientation ? " A mathematical theory of the process has been developed, which could be very briefly summarised thus : the universals turn out to be the invariants of the group of all possible perspective transformations, and their recognition involves a process called " group-scanning," which is closely analogous to scanning as employed in television. Such group-scanning units may well form permanent sub-assemblies of our brain. This speculation is supported by the fact that the sweep-rhythm which would be required for comparisons by scanning action, i.e., the time needed for direct visual comparison, is very nearly that (0·1 sec) of the so-called alpha-rhythm of the brain, as observed by the electro-encephalograph, and which is known to be of visual origin.

The cybernetical approach may also be fruitful in psychopathology. Many forms of mental disorder have no obvious anatomical basis, they are functional, and may be considered as diseases of the memory. For example, anxiety neuroses may be described in terms of certain of the circular memories occupying an increasingly large part of the total pool of neurons, thus overloading the nervous system and causing a " traffic jam." The nervous breakdown is closely analogous to that of an overloaded automatic telephone exchange, and this problem has already been studied in great detail by telecommunication engineers. The results of their

(*Concluded on page 30*)

A Series Capacitor in a 220 kV Transmission Line

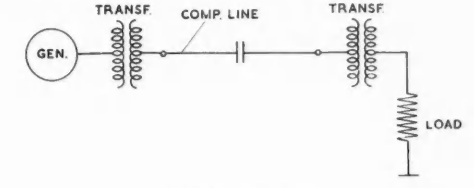
By I. HERLITZ, M. KNUDSEN and B. ZETTERSTEDT. (From *Asea Journal*, Vol. 23, No. 5-6, May-June 1950, pp. 71-88, 13 illustrations.)

Sweden's main water power resources being located in the northern provinces and its centres of consumption in the South, the Swedish high-voltage system is characterised by long transmission distances. In the existing 220-kV system, the average transmission distance is 300 miles ; when all hydro-electric power has been developed, this will be about 450 miles.

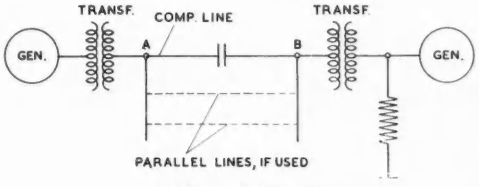
Because of such great distances, the transmission capacity of the system is determined by stability conditions ; the usual methods of increasing the static and dynamic stability limits of transmission lines have therefore been in use for many years in the Swedish transmission system : low reactance in generators and transformers, fast regulation of the excitation of generators, installation of synchronous condensers and shunt capacitors at the receiving end, high-speed tripping of relays and circuit-breakers, and automatic re-closing of circuit-breakers.

However, to increase still further the transmission capacity from the North to the South, it was decided to erect a transmission line operating at 380 kV and to equip one existing 220-kV line with series capacitors at approximately the centre of its length. Both these installations are the first of their kind in existence. The series capacitors have now been in successful operation since January 1950. The 380-kV line is nearing completion. The following contains a brief description of the series capacitor installations.

SERIES capacitors may be incorporated in power networks for two distinct purposes, depending on the nature of the network in question. In the case of distribution networks, they serve to maintain the voltage constant, whereas in high-power transmission lines they are intended to increase either their synchronous stability or the load they can carry at a certain stability level. The two different types of networks are shown diagrammatically in Fig. 1. One of the characteristic features of distribution networks is that little or no synchronous power is available on the consumer side of the capacitor. In the power transmission system, on the other hand, a considerable source of synchronous power is located at both ends of the line, i.e., on either side of the capacitor. The present article deals only with the series capacitor used in high-power transmission lines connecting synchronous generator units of large output, as shown in Fig. 1b.



(a) Distribution system



(b) Transmission system.

Fig. 1. **Different types of networks.**

Although the principle underlying this use of the series capacitor has been known for a long time, it is only comparatively recently that attention has been focussed on the possibility of using it on a large scale.

The delay in the practical application of this known principle was mainly due to disturbance phenomena which hitherto it had not been possible to master. That extensive research work has now made it possible to overcome these difficulties is borne out by the operational results of the capacitor equipment installed by the Swedish State Power Board.

This capacitor plant was installed in a 220-kV transmission line 300 miles long, at Alfta, 125 and 175 miles from the two terminal points, respectively. It is rated 31·4 MVAr at 220 kV, and has had the effect of increasing the transmission capacity of the line by 25 per cent to 175 MW without altering the stability requirements. The degree of compensation, which is the ratio of the reactance of the capacitor and that of the line, was chosen at 20 per cent : it would, however, still be economical to increase this to 30 per cent and still further to increase the carrying capacity rather than build a new transmission line.

The transmission line itself has an equivalent copper cross-section of 0·4 sq. in., a resistance of 34 ohms, and an inductance of 200 ohms at 50 cps. At 20 per cent compensation the capacitive reactance per phase at 50 cps is 40 ohms ($C = 80\mu F$). When the compensated line is fully loaded, the voltage across the capacitor is

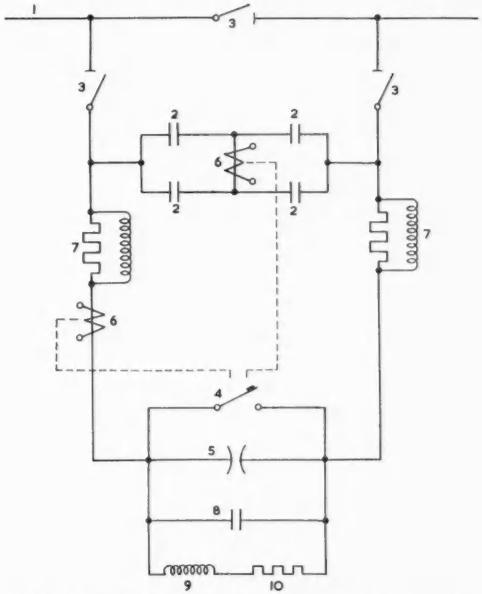


Fig. 2. **Circuit diagram of the protective equipment for one phase.**

(1) 220-kV line ; (2) capacitor ; (3) isolating switches ; (4) circuit breaker ; (5) spark gap ; (6) current transformers ; (7) damping elements ; (8) protective capacitor ; (9) discharge reactor ; (10) series resistor.

21 kV. The future extension of the capacitor plant to 30 per cent compensation, if carried out, will increase the power rating of the condenser to not less than 60 MVAr. The principal circuit diagram of the installation is shown in Fig. 2.

The capacitor installation proper consists of a large number of individual capacitor units. Those supplied by ASEA have a power rating of 33 kVAr and are designed for a voltage of 1630 V; the number of units in series per phase is 7 and the number of units in parallel per phase is 2×13.

Standard shunt capacitors were used for the installation. One of the foil electrodes in the capacitor protrudes from the paper insulation and is in direct thermal and electrical contact with the walls of the steel casing (Fig. 4). The result is a lower hot-spot temperature and, therefore, longer life than any other design of the same volume, rating and losses. The impregnating fluid is kept permanently under 2 to 3 atmospheres pressure during service by the flexible walls of the hermetically sealed casing.

Each of the sections into which the capacitor unit is divided is provided with a built-in fuse by which it is automatically disconnected should it become faulty, without causing any disruption of the operation of the installation. The erection of capacitor units is a simple matter and they may readily be installed and removed from the supporting framework, independently of one another. Each unit weighs about 100 lb. The frames are suspended by insulator strings from steel girders. The total weight of the capacitor battery is 200 tons, of which about 75 tons represents the actual capacitor units.

In the event of over-current in the transmission line, as might arise from a short-circuit somewhere on the line, the voltage across the series capacitor will rise above the normal operating voltage, causing damage to the capacitor. In order to guard against this contingency, a protective spark gap (5) is connected in parallel with the capacitor in each phase (Fig. 2). A circuit-breaker (4) also connected in parallel with the condenser serves to extinguish the arc and to by-pass the condenser when required. The protective equipment also contains

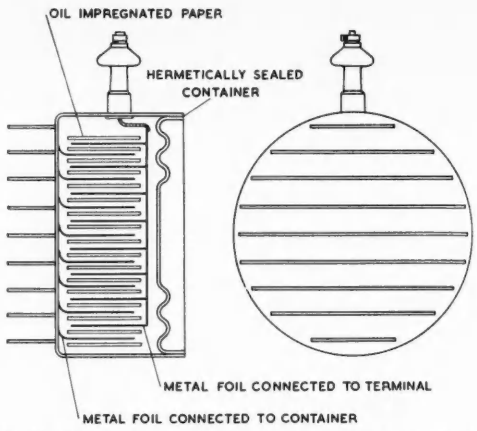

OIL IMPREGNATED PAPER
HERMETICALLY SEALED CONTAINER
METAL FOIL CONNECTED TO TERMINAL
METAL FOIL CONNECTED TO CONTAINER

Fig. 4. **Diagrammatic sketch showing the foil cooled capacitor.**

damping element (7), a discharge reactor (9) in series with a resistor (10), and a protective capacitor (8). The entire protective equipment (with the exception of the damping element and discharge resistor) is mounted on insulated platforms, one for each phase (Fig. 3). The spark gaps are of an entirely new design and are totally enclosed in a steel casing; they are designed for a peak breakdown value of 85 kV, and can carry the arc steadily for several seconds.

The protective capacitor (8) of $0{\cdot}1\mu F$ eliminates any risk of inadvertent flash-over in the gap due to atmospheric over-voltages of steep wave-front. Although the main capacitor provides fairly good protection against such flash-overs, the danger of reflection phenomena in the relatively long leads to the capacitor and spark gap makes it advisable to have a protective capacitor in the circuit adjacent to the spark gap.

The damping elements (7) in Fig 2 serve to moderate

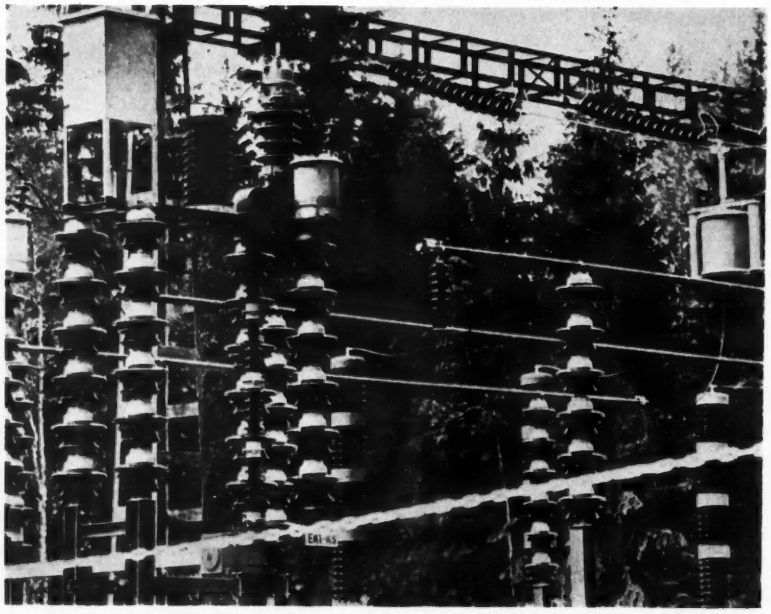


Fig. 3.

Photograph of protective equipment for one phase.

On the insulated platform can be seen from left to right :— spark gap, protective capacitor, breaker pole, and discharge reactor.

To the right of the platform :— discharge resistor.

On the extreme right :—damping element ; the large cylinder is the reactor and the slender tubes are resistors.

the capacitor discharge when the gap ignites or when the breaker is closed, and thus reduce the electrical stresses in the gap, the breaker and the capacitor. In the absence of such a damping, these discharges would give rise to oscillations of 1500 cps with very little damping. The purpose of a reactor being connected in parallel with the damping resistance is to reduce the current flowing through the latter when the circuit-breaker is closed.

The discharge reactor (9) serves to discharge any remanent energy in the capacitor, e.g., when a line circuit-breaker trips on a fault on the line not leading to flash-over at the spark gaps. As the line current will be interrupted when it passes through zero, the capacitors will remain charged at the highest capacitor voltage. When the line is switched-in again, there might be some danger of the residual d.c. charge being superimposed on the normal capacitor voltage with a consequent risk of flash-over at the spark gaps. To avoid this, the reactor is so designed that it becomes saturated within 0·01 sec. if a d.c. voltage is applied, and reduces the charge to a harmless value within about 0·3 sec.; when this happens, the current flowing through it is limited mainly by the resistor of 2000 ohms connected in series with it.

The isolating switches (3) are motor-operated and serve to isolate the whole installation from the line if required. The capacitor elements in each phase are arranged in four groups (2) forming, together with the primary of a current transformer (6), a Wheatstone bridge circuit. In case of a severe fault occurring in one of the four groups, the balance of the bridge is disturbed and a closing impulse is given to the circuit-breaker with a time delay of 1 second.

GERMANY

The Cavitation Limit in Centrifugal Pumps and Water Turbines

By C. PFLEIDERER. (From *Zeitschrift des VDI*, Vol. 92, No. 23, August 11, 1950, pp. 629-635, 7 illustrations.)

*Great care must be taken in the design of pumps and turbines to avoid the danger of cavitation. The author shows how the cavitation limit depends on the various assumptions upon which design data are based and introduces the "suction figure" which characterises this relationship. The procedure is similar to that recently proposed for the determination of the sonic barrier in centrifugal and axial-flow compressors.**

THE point of lowest vapour pressure in pumps or turbines usually occurs on the suction side of the impeller or runner blades. The pressure at this point is lower by a certain head Δh, than even the pressure at entry to, or outlet from, the wheel, and cavitation—dangerous because of the ensuing erosion of the material—therefore sets in here. Since, according to Bernoulli's principle, a point of lowest pressure is also a point of maximum speed of flow for gases, cavitation in liquids and supersonic flow of gases can be regarded as analogous phenomena, to be treated similarly for the purposes of the design of machinery. As high speeds and suction heads offer definite economic advantages, it should be attempted in the design of pumps and turbines to approach optimum conditions while just avoiding the danger of cavitation.

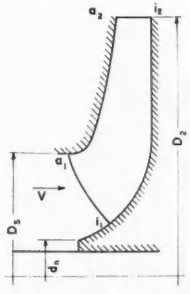


Fig. 1. **Typical form of impeller wheel.**

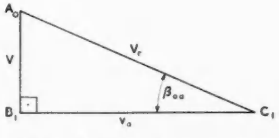


Fig. 2. **Velocity diagram for point a_1 (Fig. 1) at the suction edge of pump or turbine wheel for swirl-free entry.**

Assuming a pump impeller shaped as in Fig. 1, we can easily see that the stream filament through the outermost point of entry a_1 will first reach cavitation pressure, since the pressure drop from blade entry to the critical point (excluding any difference in datum head),

$$\Delta h = \lambda_1 \frac{V_r^2}{2g} + \lambda_2 \frac{V^2}{2g} \quad .. \quad .. \quad (1)$$

is a maximum for the maximum relative velocity $V_r = V_{ra}$ occurring at the greatest diameter D_s at blade entry. The absolute velocity V changes but little with the diameter at entry. The coefficients λ_1 and λ_2 of eq. (1) are so determined that the first term of the sum represents the pressure drop due to velocity increase from V_r at entry to the velocity at the critical point in the impeller passage, and the second term represents the additional pressure difference between the critical point and the point at which V_r can be measured. Since only the neighbourhood of point a_1 is involved in the following considerations, the calculations also apply to axial wheels, provided the diameter D_s at point a_1 (Fig. 1) is then taken to be the outer diameter of the wheel. They also apply to turbines if a_1 is regarded as a point on the outlet edge of the runner blades.

I. Flow without Swirl at Inlet.

Let the independent variable of the following calculation be the angle β_{oa} of the relative flow at point a_1 (Fig. 2). This angle determines the shape of the entire blade inlet edge and is directly related to D_s and Δh. If in eq. (1) we substitute $v_a^2 + V^2$ for V_r^2, v_a being the peripheral speed at a_1, and if we further consider that V increases, whilst v_a decreases, with decreasing D_s, it can be seen that Δh has a minimum for a certain (optimum) value of D_s and, therefore, of β_{oa}. From Fig. 2 we have

$$V_r = \frac{v_a}{\cos \beta_{oa}}, \quad V = v_a \tan \beta_{oa}, \text{ where } v_a = \frac{\pi D_s n}{60} \quad (2)$$

The volumetric flow is

$$Q = \frac{\pi}{4} D_s^2 \, k \, V = \frac{\pi}{4} D_s^2 k \frac{\pi D_s n}{60} \tan \beta_{oa}$$

so that

$$D_s = \sqrt[3]{\frac{240\,Q}{\pi^2 kn \tan \beta_{oa}}} \quad .. \quad .. \quad (3)$$

*See "The Sonic Barrier in Centrifugal and Axial Flow Compressors," *The Engineers' Digest*, September 1950, pp. 316-318.

where $k = 1 - (d_n/D_s)^2$ takes account of the reduction of cross-section, due to the hub (Fig. 1). Substituting eq. (3) into eq. (2), and eq. (2) then into eq. (1), we obtain

$$2g\,\Delta h = \left(\frac{\pi}{30^2}\,\frac{n^2 Q}{k}\right)^{2/3}\left[\frac{\lambda_1}{(\cos^2\beta_{oa}\sin\beta_{oa})^{2/3}} + \lambda_2\tan^{4/3}\beta_{oa}\right] \quad .. \quad .. \quad (4)$$

If we assume that n, Q, and k are known constants, then Δh is, in fact, a function of β_{oa} only, and the optimum value of β_{oa} is found by differentiating the term in the square brackets of eq. (4) and equating the differential quotient to zero :

$$\tan(\beta_{oa})_{opt} = \sqrt{\frac{1}{2}\,\frac{\lambda_1}{\lambda_1 + \lambda_2}} \quad .. \quad (5)$$

(*a*) *The Design of Pumps.*

Provided the outer wall near point a_1 is not too strongly curved, we may assume an average value $\lambda_1 = 0{\cdot}3$, corresponding to the value $\lambda = 0{\cdot}25$ assumed for the sonic barrier in compressors.* λ_1 is slightly higher than λ because cavitation and erosion of material are more dangerous than the effects of supersonic gas flow speeds. If friction is considered, any change in impeller dimensions is seen to cause a change in velocity head, and this change must, in effect, influence the pressure at suction entry, so that λ_2 should be assumed to be larger than unity, say 1·1 to 1·3. Substituting $\lambda_1 = 0{\cdot}3$ and $\lambda_2 = 1{\cdot}2$ in eq. (5), we obtain $(\beta_{oa})_{opt} = 17°\,32'$, i.e., a consideration of the cavitation phenomena leads to small inlet angles. We now re-write eq. (4)

$$\frac{n^2 Q}{k\,\Delta h^{3/2}} = \frac{30^2}{\pi}\left[\frac{2g}{\dfrac{\lambda_1}{(\cos^2\beta_{oa}\sin\beta_{oa})^{2/3}} + \lambda_2\tan^{4/3}\beta_{oa}}\right]^{3/2}$$

and, for ease of calculation, put

$$\left(\frac{n}{100}\right)^2\frac{Q}{k\,\Delta h^{3/2}} = S \quad .. \quad .. \quad (7)$$

The right-hand side of eq. (6) and, therefore, also the " suction figure " S are constant if β_{oa}, λ_1, λ_2 are considered to be constant. Eqs. (6) and (7) then indicate the relations between the given quantities at the cavitation limit. Except for the coefficient k and a dimensional factor, the " suction figure " S is identical with the square of the " suction specific speed." The equation S = const. thus represents a generalised principle of similarity for cavitation conditions, i.e., a principle of similarity which no longer presupposes a geometrical similarity of the impellers. For $\lambda_1 = 0{\cdot}3$ and $\lambda_2 = 1{\cdot}2$, Fig. 3 indicates the value of S as a function of β_{oa}, and from eqs. (5), (6), and (7), we obtain for $(\beta_{oa})_{opt}$:

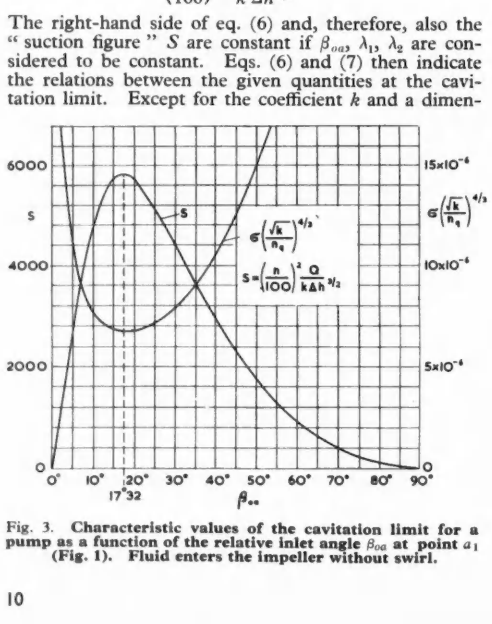


Fig. 3. **Characteristic values of the cavitation limit for a pump as a function of the relative inlet angle β_{oa} at point a_1 (Fig. 1). Fluid enters the impeller without swirl.**

According to definition, the pressure drop from suction inlet to the cavitation point on the impeller is

$$\Delta h = A - H_t - H_{s'\max} \quad .. \quad .. \quad (8)$$

where A is the (atmospheric) head on the suction water level, H_t the vapour pressure at suction temperature, $H_{s'\max}$ the maximum total suction head of the pump, from suction water level to the cavitation point, including pipe friction losses and the velocity head at the suction nozzle. If the " suction figure " S is known, we can therefore either calculate n and D_s' eq. (3), from given Q, $H_{s'\max}$, and gross lift H, or obtain the maximum possible suction head $H_{s'\max}$ from given n and Q. If the change of λ_1 and λ_2 with the Reynolds number is considered, S must be calculated from eqs. (6) and (7). We may reasonably assume that the λ-values change in inverse proportion to the hydraulic efficiency η_h; S is then proportional to $\eta^{3/2}$. It thus follows that *large pumps have a better suction efficiency than small pumps.* Furthermore, S depends on β_{oa}, λ_1 and λ_2 only, so that it also represents a measure of the quality of design and manufacture of the pump, irrespective of type or shape of the impeller, provided only that the pump is run at maximum efficiency and not at light load or overload.

The influence of the gross lift H — not appearing in eqs. (1) to (8)—is relevant only when the shape of the impeller, i.e., the specific speed $n_q = nQ^{1/2}/H^{3/4}$, is prescribed. Introducing the " cavitation ratio " $\sigma = \Delta h/H$ from Thoma's principle of similarity, and substituting σ and n_q in eq. (4), we obtain

$$\sigma = \frac{1}{2g}\left(\frac{\pi}{30^2\,k}\right)^{2/3} n_q^{4/3}\left[\frac{\lambda_1}{(\cos^2\beta_{oa}\sin\beta_{oa})^{2/3}} + \lambda_2\tan^{4/3}\beta_{oa}\right] \quad .. \quad (9)$$

and conclude that σ changes with n_q, i.e., the shape of the impeller. Eq. (9) again generalises Thoma's principle of similarity insofar as it separately illustrates the influence of the inlet angle β_{oa} on the " cavitation ratio " (Fig. 3). σ and S are connected by the relation

$$\sigma = \left[\left(\frac{n_q}{100}\right)^2\frac{1}{kS}\right]^{2/3} \quad .. \quad .. \quad (10)$$

Tests with different types of pumps show that, on the average, $S = 5300$ to 6650. The higher value, i.e., the better result, is obtained with impeller blades of double curvature and inlet edge drawn forward into the suction chamber (Fig. 1). Impeller blades of simple curvature and oblique inlet edge are less favourable, and the lower limit of S is obtained with blades of simple curvature and an inlet edge parallel to the axis. S is shown to decrease with an increasing number of blades because of the increasingly greater reduction of cross-sectional area behind the inlet edge. On the other hand, a three-bladed impeller had a fairly low $S = 5480$, probably due to the small number of blades. In all these tests, S has been calculated from given data by means of eq. (7), with the pump running at highest efficiency,

TABLE I.—"SUCTION FIGURES" S FOR FRANCIS TURBINES AND FOR KAPLAN TURBINES WITH ADJUSTABLE GATES AND BLADES, AS CALCULATED FROM KNOWN SERVICE DATA FOR MAXIMUM DISCHARGE.

	Francis turbines					Kaplan turbines		
n_s	11·25	22·5	45	67·5	100	100/110	125/135	160/180
σ	0·03	0·05	0·11	0·20	0·46	0·4/0·45	0·6/0·65	1·05
η	0·78	0·82	0·83	0·83	0·83	0·83	0·84	0·85
S	10250	18500	21800	20300	12800	19600 to 20000	16200 to 18700	11200 to 14500

and small deviations of β_{oa} from the optimum value have been neglected. It is important to note that an appreciable reduction of cross-sectional area behind the inlet edge, rough impeller walls, small-capacity designs, as well as noticeable deviations from $(\beta_{oa})_{opt}$, all influence the result unfavourably.

Numerical Example : A centrifugal pump with impeller blades of simple curvature discharges 1320 gpm when running at 950 rpm. In order to calculate the maximum suction head, we first assume $S = 5300$, $k = 0{\cdot}75$. Then, from eq. (7), $\Delta h = 9{\cdot}7$ ft. For a lowest atmospheric pressure of A = 31·2 ft of water, and a vapour pressure of cold water of $H_f = 0{\cdot}65$ ft, we thus have, from eq. (8), $H_s'_{max} = 20{\cdot}85$ ft, measured at point a_1. The suction head to centre of pump axis is therefore $20{\cdot}85 - D_s/2$ feet. This example shows the simplification introduced by the use of S. Since even axial flow impellers have similar S-figures, such calculations can be used quite generally.

(*b*) *The Design of Water Turbines.*

The same equations and considerations apply to turbines with a discharge normal to the direction of rotation. Point a_1 is then a point on the outlet edge of the runner blading, and $H_s'_{max}$ again the datum head of point a_1 above tail water level. λ_1 and λ_2 are smaller than for pumps because friction acts in the opposite direction and the discharge velocity head cannot wholly be recovered in the draft tube. The average "suction figure" is thus considerably higher for turbines than for pumps. If we take as a basis the usual data from turbine experience, i.e., the cavitation ratio σ, the specific speed for unit power

$$n_s = n\,P^{1/2}/H^{5/4} = 1{\cdot}74\sqrt{\eta}\,(n_q/100),$$

and the efficiency η, then the "suction figure" S can be calculated from eq. (10). We may assume $k = 1$ for the Francis turbine, where the hub does not reach into the draft tube, and $k = 0{\cdot}8$ for the Kaplan turbine with its large hub. The turbine data are usually given for maximum discharge, and not for nominal loading, so that S will also refer to maximum discharge, and not to optimum conditions with exactly vertical discharge. Although the calculated "suction figures" are thus smaller than the theoretical figures, they are nevertheless far higher for turbines (Table I) than for pumps, and it follows that *a rotor running as a turbine is less sensitive to cavitation than the same rotor used in a pump.*

The Table shows that Francis turbines with low n_s have low "suction figures". This is understandable because the outlet edges of such turbines lie in the transition zone from radial to axial flow so that the diameter at point a_1 is increased. A Francis runner of high n_s (about 100), on the other hand, widens out conically near the outlet edge, so that a new unfavourable effect again reduces S. Kaplan turbines show favourable "suction figures" for the lower range of their specific speeds. In the higher range, the propeller blades are so far apart that λ_1 increases appreciably, as is also shown by flow tests with single blades. A comparison of Francis and Kaplan turbines of identical n_s of about 100 shows clearly that the restriction of cross-section in the Francis turbine is responsible for the lower "suction figure."

In practice, the calculation of the cavitation limit of water turbines is based on the unfavourable maximum discharge conditions. The S-values of Table I can, therefore, well be used ; they are more advantageous than the σ-values because they change but slightly with the specific speed. A comparison with the corresponding pump impellers—which would be more sensitive to cavitation—admits, moreover, of a clearer estimate of the relative merits of different wheel shapes. Since friction in turbines acts in the opposite direction to that in pumps, large turbines are more sensitive to cavitation than smaller turbines. The optimum angle β_{oa} is again about 18 degrees.

Flow with Swirl at Inlet.

Let
$$C = 1 - \frac{V_w}{v_a} \qquad .. \qquad .. \quad (11)$$

be the "relative whirl component," on which calculations are to be based. From Fig. 4, we then have at the point a_1 the relative velocity

$$V_r = \frac{v_a - V_w}{\cos\beta_{oa}} = v_a\,\frac{C}{\cos\beta_{oa}} \qquad .. \quad (12)$$

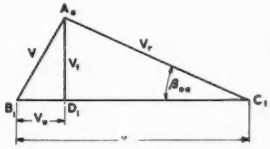


Fig. 4. Velocity diagram for point a_1 (Fig. 1) of the suction edge if the flow on suction side has a whirl component V_w.

and can calculate the absolute velocity from

$$V^2 = V_f^2 + V_w^2 = (v_a - V_w)^2\tan^2\beta_{oa} + (1-C)^2 v_a^2$$
$$= v_a^2\,[C^2\tan^2\beta_{oa} + (1-C)^2] \qquad .. \quad (13)$$

where
$$v_a = \pi D_s n/60 \qquad .. \qquad .. \qquad .. \quad (14)$$

The condition of continuity now leads to the relation

$$D_s = \sqrt[3]{\frac{240\,Q}{\pi^2\,k\,n\,C\tan\beta_{oa}}} \qquad .. \qquad .. \quad (15)$$

$k = 1 - (d_n/D_s)^2$ again characterises the restriction of cross-section due to the hub. Introducing eq. (15) into eq. (14), the resulting value for v_a into eqs. (12) and (13), and the latter then into eq. (1), we find

$$2g\,\Delta h = \left(\frac{\pi}{30^2}\,\frac{n^2Q}{k}\right)^{2/3}\left[\lambda_1\left(\frac{C^2}{\cos^2\beta_{oa}\sin\beta_{oa}}\right)^{2/3} + \lambda_2\,\frac{(C\tan\beta_{oa})^2 + (1-C)^2}{(C\tan\beta_{oa})^{2/3}}\right] \qquad .. \quad (16)$$

or, slightly transformed,

$$2g\,\Delta h = \left(\frac{\pi}{30^2}\,\frac{n^2Q}{k}\right)^{2/3}\frac{C^2\dfrac{\lambda_1+\lambda_2}{\cos^2\beta_{oa}} + \lambda_2(1-2C)}{(C\tan\beta_{oa})^{2/3}} \qquad (17)$$

The "suction figure" S is now

$$S = \left(\frac{n}{100}\right)^2\frac{Q}{k\,\Delta h^{3/2}} = \frac{0{\cdot}09}{\pi}\times$$
$$\times\left[\frac{2g}{\left(\lambda_1\dfrac{C^2}{\cos^2\beta_{oa}\sin\beta_{oa}}\right)^{2/3} + \lambda_2\dfrac{(C\tan\beta_{oa})^2+(1-C)^2}{(C\tan\beta_{oa})^{2/3}}}\right]^{3/2} \qquad (18)$$

and the "cavitation ratio" σ follows from eq. (10). If

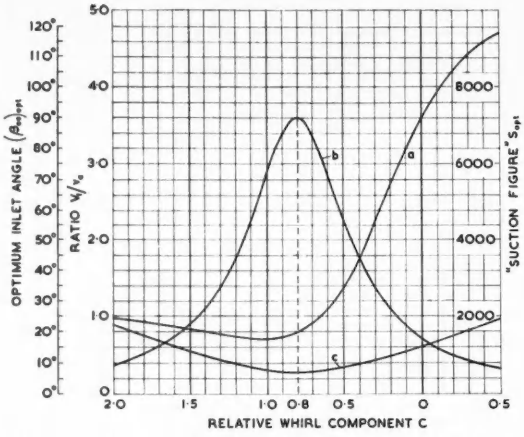


Fig. 5. **Optimum values of coefficients characterising the cavitation limit of a pump, as a function of the "relative whirl component"** $C = 1 - V_w/V_a$.
Curve a = Optimum inlet angle $(\beta_{oa})_{opt}$ at point a_1 of blade edge.
Curve b = Optimum value of "suction figure," S_{opt}.
Curve c = Ratio V_f/v_a.

we assume C = const., differentiating the quantity in the square brackets of eq. (18), and equating the differential to zero, we finally have

$$\tan (\beta_{oa})_{opt} = \pm \sqrt{\frac{1}{2} \frac{\lambda_1 + \lambda_2 \left(\frac{1}{C} - 1\right)^2}{\lambda_1 + \lambda_2}} \quad .. \quad (19)$$

Δh is again given by eq. (8).

(*a*) *The Design of Pumps.*

Curve *a*, Fig. 5, shows the optimum inlet angle $(\beta_{oa})_{opt}$ for $\lambda_1 = 0{\cdot}3$ and $\lambda_2 = 1{\cdot}2$ as a function of the "relative whirl component" C. The curve has a minimum of 17° 32′ as before, for $C = 1$. It follows that *any tangential component of the velocity at inlet, whether in the direction of, or opposite to, the impeller rotation, requires an increase in inlet blade angle.* For $C > 1$, i.e., an anti-rotational velocity component, the velocity of flow V_f so increases that D_s must be reduced —see also eq. (15). For $C < 1$, $(\beta_{oa})_{opt}$ increases rapidly and reaches 90 degrees when $C = 0$, i.e., $V_w = v_a$. In hydraulic torque converters, $(\beta_{oa})_{opt}$ increases further with negative C, and the negative value of eq. (19) is then valid. The optimum "suction figure"

$$S_{opt} = \frac{\left(\frac{n}{100}\right)^2 Q}{k\, \Delta h^{3/2}} = \frac{a\,(2g)^{3/2}}{\sqrt{\lambda_1 + \lambda_2}\ [\lambda_1 C^2 + \lambda_2 (1 - C)^2]} \quad (20)$$

obtained by substitution of eq. (19) in eq. (18) and shown as curve *b* in Fig. 5, has a maximum where the differential of the square bracket of eq. (20) is zero, i.e., for $C_{opt} = \lambda_2/(\lambda_1 + \lambda_2) = 0{\cdot}8$. This maximum,

$$(S_{opt})_{max} = a\,(2g)^{3/2} \frac{\lambda_1 + \lambda_2}{\lambda_1 \lambda_2} = 7170$$

(for $\lambda_1 = 0{\cdot}3$, $\lambda_2 = 1{\cdot}2$), is 24 per cent greater than the corresponding value of eq. (7a). Hence, *by using inlet guide vanes giving a slight tangential component of flow in the direction of wheel rotation, the suction of a pump can be noticeably improved, or cavitation avoided* ; at the same time, the hydraulic efficiency is increased. On the other hand, an anti-rotational tangential component, even if small, always reduces the suction head and diminishes the efficiency.

Curve *c*, Fig. 5, represents the ratio $(V_f/v_a)_{opt} = C \tan (\beta_{oa})_{opt}$ and thus illustrates the change of the velocity of flow V_f, for optimum inlet angle, with the "relative whirl component" C. V_f has a minimum for $C = 0{\cdot}8$, i.e., for a slight tangential component of flow in the direction of wheel rotation, and increases if the entering fluid is given an anti-rotational tangential component. Finally, another design value frequently used,

$$\frac{v_a}{\sqrt{2g\,\Delta h}} = b \sqrt[3]{\frac{S}{\tan \beta_{oa}}} \quad .. \quad .. \quad (21)$$

where b is a dimensional constant, follows S closely.

(*b*) *The Design of Water Turbines.*

Let us first assume that at full load a given turbine with fixed blading (β_{oa} = const.) discharges a water volume Q with a velocity of flow $V = V_f$ having no tangential component. At light loads, the discharged water then has a tangential velocity component in the direction of runner rotation, whilst at overload, the tangential component opposes the runner rotation.

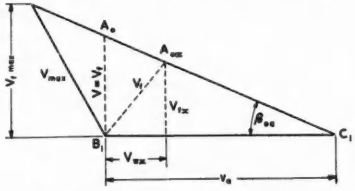


Fig. 6. **Relationship between the tangential component** V_{wx} **at outlet from water turbine runner and the volume discharged, i.e., the velocity of flow** V_{fx}.

From Fig. 6 we find that the volume discharged at any given load x can be determined from the ratio

$$\frac{Q_x}{Q} = \frac{V_{fx}}{V_f} = \frac{v_a - V_{wx}}{v_a} = C,$$

i.e., by means of the "relative whirl component" C. Since β_{oa} is fixed, Fig. 5 no longer applies, and a new quantity must be chosen to characterise the suction qualities of the turbine at various loads, e.g.,

$$\frac{2g\,\Delta h}{v_a^2} = \frac{2g\,(A - H_t - H_s'_{max})}{v_a^2} = \left(\frac{C}{\cos \beta_{oa}}\right)^2 (\lambda_1 + \lambda_2) + \lambda_2 (1 - 2C) \quad .. \quad (22)$$

as can be derived from eq. (8), and from eq. (17) with eqs. (14) and (15) respectively. For $\lambda_1 = 0{\cdot}2$, $\lambda_2 = 0{\cdot}7$, $\beta_{oa} = 20°$, this quantity has a minimum for $C = 0{\cdot}708$, i.e., if the discharged water has a noticeable tangential component in the direction of runner rotation. Since this minimum corresponds to a maximum suction head $H_s'_{max}$, it is the most favourable value. The value of eq. (22) increases at very light loads and especially heavily at overloads. The suction head is therefore reduced, and the danger of cavitation greatest, at overloads. The above considerations cannot directly be applied to turbines with adjustable blading. For the design of a water turbine, however, i.e., for the choice of the best values β_{oa} and C at the intended service load, Fig. 5 may serve as a guide, always on the understanding that turbines have much reduced λ-values. The design should thus be based on a moderate tangential velocity component of the discharged water in the direction of runner rotation.

Power as a Function of the Torque Angle in Three-Phase Synchronous Machines

By E. PETZOLDT. (From *Elektrotechnik und Maschinenbau*, Vol. 67, No. 10, October, 1950, pp. 304-308, 5 illustrations.)

This article investigates the power variations of the three-phase synchronous machine under sudden load variations. The vibration amplitudes and power fluctuations are determined by a step-by-step method.

THE machine subjected to a sudden load variation can be regarded as a vibrating system with a mass m, a stiffness k and a damping coefficient c. If ΔP is the load impulse acting on the system, the equation of motion will be

$$m\ddot{x} + c\dot{x} + kx = \Delta P \quad .. \quad .. \quad (1)$$

where x = amplitude of half total swing. The two partial solutions are

$$x_1 = x_0\, e^{-\gamma t} \sin(\omega t + \varphi) \; .. \quad .. \quad (2)$$

and $$x_2 = P/k = x_s \quad .. \quad .. \quad (3)$$

The amplitude is, therefore,

$$x = x_1 + x_2 = x_0\, e^{-\gamma t} \sin(\omega t + \varphi) + x_s \; .. \quad (4)$$

Thus, x_0 is the maximum amplitude of the damped vibration at time $t = 0$. The relative damping is $\gamma = c/(2m)$ and the angular velocity of the vibration is given by $\omega = \sqrt{(k/m) - \gamma^2}$. As γ is small, we can regard the frequency as being determined by $\omega = \sqrt{k/m}$, so that the period of each vibration cycle will be $T = 2\pi/\omega$.

The boundary conditions $\dot{x}(0) = 0$ and $x(0) = x_0$ in conjunction with eq. (4) give the solution

$$x = x_s(1 - e^{-\gamma t} \cos \omega t) \; .. \quad .. \quad (5)$$

so that $$\dot{x} = x_s(\gamma\, e^{-\gamma t} \cos \omega t + \omega\, e^{-\gamma t} \sin \omega t)$$

The first term in the brackets can be omitted, since γ is small, and we then have

$$\dot{x} = x_s\, \omega\, e^{-\gamma t} \sin \omega t \quad .. \quad .. \quad (6)$$

It will be useful to express the time t as a fraction or multiple of the period T of the vibration by writing

$$t = nT \quad \text{and} \quad t = 2\pi n$$

where n is a positive number, such as $1/8, 1/4, 3/8, \ldots$.

Furthermore, if $\delta = \gamma T$ denotes the logarithmic decrement, we can then re-write eqs. (5) and (6) as follows :

$$x = x_s(1 - e^{-n\delta} \cos 2\pi n) \quad .. \quad (7)$$

$$\dot{x} = x_s\, \omega\, e^{-n\delta} \sin 2\pi n \quad .. \quad .. \quad (8)$$

The sum of the resisting forces $y_1 = kx$ and $y_2 = c\dot{x}$ will now be calculated. We have

$$y = y_1 + y_2 = kx + c\dot{x} \quad .. \quad (9)$$

As $$c\dot{x} = c\omega\, x_s\, e^{-n\delta} \sin 2\pi n$$

$$= c\omega\,[x_s^2\, e^{-2n\delta} - x_s^2\, e^{-2n\delta} \cos^2 2\pi n]^{1/2}$$

and $$x_s^2\, e^{-2n\delta} \cos^2(2\pi n) = (x_s - x)^2 \quad .. \quad (10)$$

from eq. (7), substituting this in the equation for $c\dot{x}$ gives

$$c\dot{x} = c\omega\,[x_s^2\,(e^{-2n\delta} - 1) + 2x_s\, x - x^2]^{1/2} \; .. \quad (11)$$

Therefore, combining eqs. (9) and (11), we obtain :

$$(k^2 + c^2\omega^2)\, x^2 - 2c^2\omega^2 x_s\, x + y^2 - 2kxy$$
$$- c^2\omega^2 x_s^2\,(e^{-2n\delta} - 1) = 0 \quad .. \quad .. \quad (12)$$

Equation (12) shows the variation of the vibration during the starting period, as a function of the amplitude x, under a sudden load impulse ΔP. The value of x is determined from eq. (7). The values of x and y thus obtained are for zero preload. The preload effect is calculated separately : If at $t = 0$ there is a steady preload P_1, then this corresponds to a deflection $a_1 = P_1/k$. The total amplitude a of the vibration is then

$$a = a_1 + x \quad .. \quad .. \quad (13)$$

and the corresponding ordinate in the P-a diagram is

$$P = P_1 + y \quad .. \quad .. \quad (14)$$

By substituting successively various fractional values for n in eq. (7) we can construct the P-a diagram shown in Fig. 1 with the aid of eqs. (12), (13) and (14).

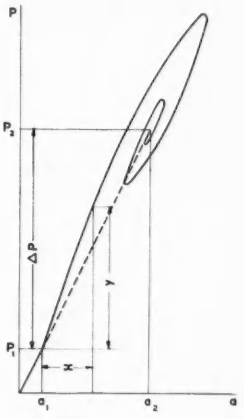


Fig. 1

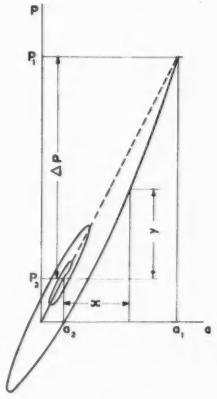


Fig. 2

Conversely, if the load is dropped by a value ΔP, then in accordance with eq. (1) :

$$x = x_s\, e^{-n\delta} \cos 2\pi n \quad .. \quad .. \quad (15)$$

and $$y = kx - c\,\omega\,[x_s^2\, e^{-2n\delta} - x^2]^{1/2} \quad .. \quad (16)$$

so that

$$(k^2 + c^2\omega^2)\, x^2 + y^2 - 2kxy - c^2\omega^2 x_s^2\, e^{-2n\delta} = 0 \quad (17)$$

If ΔP is only a partial load drop from a value P_1 to P_2, so that $P = P_1 - P_2$, the final steady deflection will be $a_2 = P_2/k$. Taking the residual load into account, the total resultant amplitude of the vibration at any instant will, therefore, be

$$a = a_2 + x \quad .. \quad .. \quad (18)$$

where x is determined from eq. (15), and the corresponding force P figuring as ordinate in the P-a diagram is

$$P = P_2 + y \quad .. \quad .. \quad (19)$$

where y is obtained from eq. (17). The load-drop variation is shown in Fig. 2.

The transients due to damped vibrations of three-phase synchronous machines are governed by the equation

$$\frac{J\,\omega_s}{p^2}\ddot{\xi} + \frac{N_n}{\omega_s\, s_n}\dot{\xi} + N_s\,\xi = \Delta N \quad .. \quad (20)$$

which is similar to eq. (1). In this equation, each term is expressed in watts. The first term represents the acceleration of the rotor, the 2nd and 3rd terms are the asynchronous and synchronous power, taken with a negative sign, while ΔN is the sudden change in load. Furthermore : $\mathcal{J}$ = mass moment of inertia of all the rotating masses [kg (weight) m sec^2] ; ω_s = synchronous electrical angular velocity [rad/sec] ; N_n = rated power [watts] ; s_n = slip, for which the machine gives the rated power in asynchronous operation ; N_s = synchronizing power [watt/rad] ; p = no. of pole pairs ; ξ = the instantaneous torque angle which corresponds only to the actual amplitude of the vibration [rad] ; $\dot{\xi}$ and $\ddot{\xi}$ = angular velocity and acceleration of the transient vibration, [rad/sec] and [rad/sec^2].

A comparison of eqs. (1) and (20) shows that N_s is now used in place of the stiffness k. However, N_s is constant only over a small angle $\Delta\xi$. For a non-salient pole machine, the synchronizing power may be expressed as a percentage $N^\star$ of the rated power. The rated power being $N_n = 3\ U_n\ I_n$, the synchronizing power in per cent is then

$$N^\star = 10^4 \left(\frac{U}{U_n}\right)^2 \frac{E \sin\theta}{U\, x_m^\star} \quad .. \quad (21)$$

When operating at rated voltage, $U = U_n$. E is the internal voltage ; $x_m^\star = x\, I_n \times 100/U_n$ = synchronous reactance in percent ($x_m = x_a + x_s$ = armature reactance and stray reactance) ; θ = resultant torque angle, taking account of the preload. The synchronizing power in per cent is, therefore,

$$N_s^\star = dN^\star/d\theta = 10^4(U/U_n^2\, x_m^\star)\,[\sin\theta\,(dE/d\theta) + E\cos\theta] \quad .. \quad (22)$$

For salient pole machines, we have

$$N^\star = 10^4\,(U/U_n)^2 \left[E\sin\theta/(X_{ls}^\star\, U) + \left\{X_{ls}^\star \sin 2\theta/(2\, X_{ls}^\star\, X_{qs}^\star)\right\}\right] \quad .. \quad (23)$$

where

$X_{lq}^\star = (x_l - x_q)^\star$, $X_{ls}^\star = (x_l + x_s)^\star$, $X_{qs}^\star = (x_q + x_s)^\star$, x_l and x_q being the longitudinal and transverse reactances.

Therefore,

$$N_s^\star = dN^\star/d\theta = 10^4\,(U^2/U_n^2\, X_{ls}^\star\Big[\left\{(\sin\theta\, dE/(U d\theta) + E\cos\theta/U\right\} + \left\{X_{lq}^\star \cos 2\theta/X_{qs}^\star\right\}\Big] \quad .. \quad (24)$$

In eqs. (22) and (24), $dE/d\theta$ is in volt/rad.

Equation (20) can now be re-written with each term expressed as a percentage of the nominal power N_n. Furthermore, ξ, ω_s, $\dot{\xi}$ and $\ddot{\xi}$ will be expressed in degrees instead of radians, with the result that eq. (20) becomes :

$$\left(\frac{\pi}{180}\right)^2 \frac{\mathcal{J} g\ \omega_s}{p^2} \frac{100}{N_n} \ddot{\xi} + \frac{100}{\omega_s\, s_n} \dot{\xi} + \frac{\pi}{180} N_s^\star = \Delta N^\star \quad .. \quad (25)$$

where $\omega_s = 360(pn/60)$ is the synchronous angular velocity in degrees, and n = running speed [rpm]. A comparison of eqs. (1) and (25) shows that the damping factor is

$$\gamma = 1/(2T_A\, s_n) \quad .. \quad .. \quad (26)$$

where T_A is the starting time constant :

$$T_A = \pi^2\, \mathcal{J}\, \omega_s^2/(180^2\, N_n\, p^2) = \pi^2\, n^2\, GD^2/(60^2\, N_n) \quad (27)$$

and GD^2 [tonnes-metres] is the swinging moment of all the rotating masses. In eq. (27) N_n is expressed first in watts and then in kVA.—The angular velocity of the oscillation, obtained by comparing eqs. (1) and (25), is

$$\omega = 0{\cdot}1\sqrt{\pi\, \omega_s\, N_s^\star/(180\ T_A)} \quad .. \quad (28)$$

where $\omega_s = 360(pn/60)$. The logarithmic decrement is

$$\delta = 10\sqrt{180\pi}/(s_n\sqrt{T_A\, \omega_s\, N_s^\star}) \quad .. \quad (29)$$

Denoting by ξ the abscissa and by η the power used as ordinate, we obtain in the same way as for eq. (7) :

$$\xi = \frac{180}{\pi} \frac{\Delta N^\star}{N_s^\star} [1 - e^{-n\delta} \cos 2\pi n] \quad .. \quad (30)$$

and using the resultant relationship of eq. (12), the damped vibration conditions of the suddenly-loaded three-phase synchronous machine are represented by

$$\left(\frac{\pi}{180} N_s^\star\right) [(\pi N_s^\star/180) + (100/\omega_s\, s_n^2\ T_A)]\ \xi^2 - 2 \times 100\,(\Delta N^\star/\omega_s\, s_n^2\ T_A) + \eta^2 - (2\,\pi N_s^\star/180)\,\xi\eta - 180 \times 100\,(\Delta N^\star)^2\,(e^{-2n\delta} - 1)/(\pi\,\omega_s\, s_n^2\, T_A\, N_s^\star) = 0 \quad (31)$$

Eq. (30) gives ξ in degrees and eq. (31) gives η as a percentage of the rated power. The preload is calculated separately, since the synchronizing power can only be regarded as constant over a small angle $\Delta\xi$. The values of $\Delta\xi$ and $\Delta\eta$ are obtained by taking the differences of values determined from eqs. (30) and (31), so that it is therefore simpler to consider the preload separately. The total resultant displacement is thus

$$\theta = \theta_1 + \Sigma\Delta\xi \text{ [degrees]}, \quad .. \quad (32)$$

and

$$N = N_1 + \Sigma\Delta\eta \quad .. \quad .. \quad .. \quad (33)$$

represents the resultant corresponding power as a percentage of the rated power. The variation of the transient vibration is shown in the diagram of Fig. 3.

Putting $\Delta N^\star = 0$ in eq. (25), we obtain, in the same way as for eqs. (15) and (16), the vibration conditions corresponding to a load drop :

$$\xi = 180\ \Delta N^\star/(\pi N_s^\star)\ e^{-n\delta} \cos 2\pi n \quad .. \quad (34)$$

and

$$(\pi/180)\ N_s^\star\ [(\pi/180)\ N_s^\star + (100/\omega_s\, s_n^2\ T_A)]\ \xi^2 + \eta^2 - (2\,\pi N_s^\star/180)\,\xi\eta - [180 \times 100(\Delta N^\star)^2/(\pi\omega_s\, s_n^2\, T_A\, N_s^\star)]\, e^{-2n\delta} = 0 \quad (35)$$

The values of $\Delta\xi$ and $\Delta\eta$ are again obtained by taking differences of ξ's and η's determined by means of eqs. (34) and (35). In the case of a load drop, therefore, the $\Delta\xi$ and $\Delta\eta$ terms should be counted beginning from the preloaded condition. The diagram is then constructed with the resultant values : $\theta = \theta_1 + \Sigma\Delta\xi$ and $N = N_1 + \Sigma\Delta\eta$, as shown in Fig. 4. A comparison of Fig. 4 and Figs. 2 and 3 shows that the synchronizing power $N_s^\star$ remains constant during the load drop.

The step-by-step method used will now be illustrated by applying it to Fig. 3. The static power characteristic N_1, with the preload θ_1, is given. Then $N_s^\star$ is determined for $\theta = \theta_1$ from eq. (22) or (24) and $E = E_1$ is obtained from the voltage characteristic. As $dE/d\theta$ is still unknown, the corresponding term is omitted at this stage. For a given value of $N_s^\star$ we obtain $\Delta N^\star$, and a first value for $\Delta\xi_1$ from eq. (34). The whole vibration is subdivided, for instance, into eight intervals. Then using $n = 1/8$, $\Delta\xi_1$ can be determined. The time element Δt_1 corresponding to $\Delta\xi_1$ is then found from eq. (28) and is given by $\Delta t = 2\,\pi/(\omega z)$, where $z = 8$ in the present case. Knowing $\Delta\xi_1$ and Δt_1, the change of voltage in the excitation circuit is obtained from†

$$\Delta e_2 = -10^{-8}\, w_2\, \Phi_0\, (\Delta\xi/\Delta t)\, \sigma_2 \sin\theta/(1 + \sigma_L) \quad .. \quad (36)$$

where w_2 = no. of turns in the exciter winding, Φ_0 = flux entering the stator with zero-load excitation of the

† For derivation, see E.u.M., Vol. 67, 1950, p. 41.

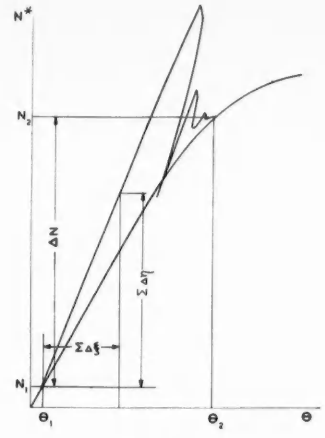


Fig. 3

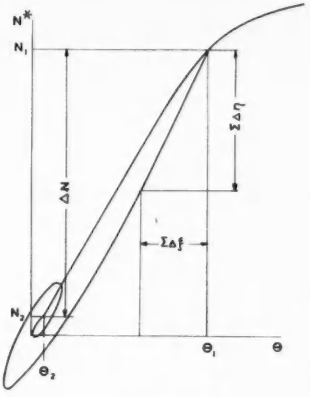


Fig. 4

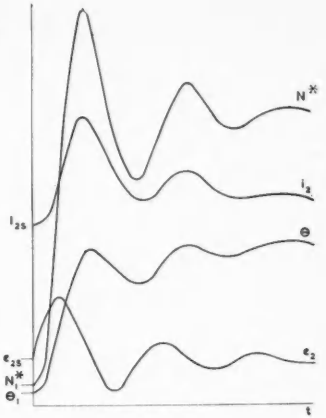


Fig. 5

rotor, σ_2 = stray field coefficient of exciter winding and

$$\sigma_L = \sigma_2\,\sigma_3/(\sigma_2 + \sigma_3) \quad .. \quad .. \quad (37)$$

= stray field coefficient of the rotor, with σ_3 = stray field coefficient of the damping winding. In eq. (36), we substitute $\theta = \theta_1 + \Delta\xi$, $\Delta\xi = \Delta\xi_1$ and $\Delta t = \Delta t_1$, and obtain for the change of the excitation current at the end of the first time or angle element :

$$\Delta i_2 = \Delta e_2\,[\Delta t - T_s\,(1 - e^{-t/T_s})]/(r_2\,\Delta t) \quad .. \quad (38)$$

after putting $\Delta t = \Delta t_1$; r_2 is the ohmic resistance in the excitation circuit after warming up to operating conditions and T_s is the stray field time constant, which is given by :

$$T_s = [T_{01}\,T_{02}\,\sigma_{12} + T_{01}\,T_{03}\,\sigma_{13} + T_{02}\,T_{03}\,\sigma_{23}]/(T_{01} + T_{02} + T_{03}) \quad .. \quad (39)$$

In this equation, $T_{02} = 10^{-8}\,w_2\,\Phi_0\,(1 + \sigma_2)/(i_{20}\,r_2)$ = no-load time constant of the exciter winding, with i_{20} = no-load exciter current ; $T_{01} = T_{02}$ = no-load time constant of stator winding ; and $T_{03} = 0{\cdot}3\,T_{02}$ = no-load time constant of the damping winding. In the above, T_{02} and r_2 are determined for the cold machine. The total stray field coefficients are given by

$$\left.\begin{aligned} \sigma_{12} &= 1 - \{1/[(1 + \sigma_1)\,(1 + \sigma_2)]\} \\ \sigma_{13} &= 1 - \{1/[(1 + \sigma_1)\,(1 + \sigma_3)]\} \\ \text{and} \quad \sigma_{23} &= 1 - \{1/[(1 + \sigma_2)\,(1 + \sigma_3)]\} \end{aligned}\right\} \quad (40)$$

Denoting the steady excitation current by i_{2s}, we obtain with eq. (38) the change of the internal voltage at the end of the first angular element as $\Delta E_1 = E_1\,\Delta i_2/i_{2s}$. This gives $dE/d\theta = \Delta E_1/\Delta\xi_1$ for this angle element. The value of N_s* can now be calculated again using eq. (22) or (24), until the result is in agreement with the final value of $dE/d\theta$. Using the final $\Delta\xi_1$ we determine $\Delta\eta_1$ with eq. (31). For the following angle element $\Delta\xi_2$ we substitute first in eq. (22) or (24) the values $E = E_1 + \Delta E_1$, $\theta = \theta_1 + \Delta\xi_1$, and use temporarily the value of $dE/d\theta$ from the previous angle element. This gives an approximate value for N_s*. The value of $\Delta\xi_2$ and those of the following elements are found by taking differences. Thus, $\Delta\xi_2 = \xi_{n=\frac{2}{k}} - \xi_{n=\frac{1}{k}}$, etc., and the same process is repeated for the determination of $\Delta\eta_2$, with the aid of eq. (31), after finding the final value of N_s* for the second angle element. For this, after substituting $\theta = \theta_1 + \Delta\xi_1 + \Delta\xi_2$ in eq. (36), we set $\Delta\xi = \Delta\xi_2$, and $\Delta t = \Delta t_2$ in connection with eq. (28). Finally, eq. (38) gives the new increase in current in the exciter circuit. A further calculation determines ΔE_2, the change of the internal voltage in the second angular element. The calculation is repeated for this angular element, until N_s* is in agreement with the value of $dE/d\theta = \Delta E_2/\Delta\xi_2$ found subsequently by means of eq. (22) or (24).

Fig. 5 shows the variation of the machine characteristics plotted against time, on the basis of the results given in Fig. 3. The variables shown are :—

$N^* = N_1^* + \Sigma\Delta\eta^*$, $\theta^\circ = \theta_1^\circ + \Sigma\Delta\xi^\circ$, $i_2 = i_{2s} + \Delta i_2$

and $e_2 = e_{2s} + \Delta e_2$, where e_{2s} is the steady exciter voltage.

Calculations and tests show that the synchronizing power N_s* increases steadily during the forward vibration of the rotor. The cosine terms in eqs. (22) and (24) decrease with larger torque angles θ, but the increase of the terms with $dE/d\theta$ is considerable, and results in an increase of N_s* in spite of the reduced cosine terms. When the rotor is swinging back, the cosine terms increase, while the terms with $dE/d\theta$ also grow larger. This can be seen in Fig. 5 by comparing the θ-line with the i_2-line. In this figure, for the same value of i_2 (and hence of E) on either side of a maximum, the corresponding torque angle of the forward vibration of the rotor is smaller than that of the return swing ; consequently $dE/d\theta$ is greater during the return stroke. Owing to the high value of the synchronizing power and in agreement with eq. (30), a moderate swing-back effect of the rotor will occur. Both calculations and tests have shown that the period of the vibration decreases with increasing shock loads and also decreases with higher preloads.

The period T may be calculated first for each angular element, from eq. (28) and from $T = 2\pi/\omega$, the mean value being subsequently determined for the entire vibration. The high excitation capacity of the three-phase synchronous machine under a sudden load application is also a factor to be considered. The excitation capacity is the ratio between the rotor voltage before the first reversal point of the rotor and the steady rotor voltage. The time required for this excitation to be achieved is less than the time constant of the machine. A shock excitation of the exciter machine for stabilisation of the three-phase machine during vibration periods would, however, be ineffective, at least during the first outward oscillation. The stabilisation of the machine during this first part of the vibration process takes place exclusively as a result of the reaction effects occurring in the machine itself. A further improvement of this dynamic stability under sudden load variations is obtained with the decreased reactances of the system.

U. S. A.

A Domestic Heat Pump Water Heater

Report of the JOINT AEIC-EEI HEAT PUMP COMMITTEE.

(From *Edison Electric Institute Bulletin*, Vol. 18, No. 10, October, 1950, pp. 379-381, 5 illustrations.)

INTEREST in the use of year-round heat pump air conditioning units, which has been increasing among manufacturers and consumers during the past ten years, has overshadowed the interest of a smaller group in the possibility of utilizing the heat pump principle for the supply of domestic hot water. However, some equipment manufacturers, research organisations, and utility research departments have made theoretical studies and basic laboratory investigations of this possibility ; in a few cases, actual laboratory models were assembled and tested under controlled conditions. In 1949, one manufacturer presented a proposal to a number of electric utilities for the production of a limited number of pilot model units for field test purposes. As a result of this, twenty-five heat pump water heaters were ordered and installed. At the time of writing, these had been in operation for periods of 7 to 118 days.

Fig. 1 shows, diagrammatically, the arrangement of the water heater and of the test instruments. Fig. 2

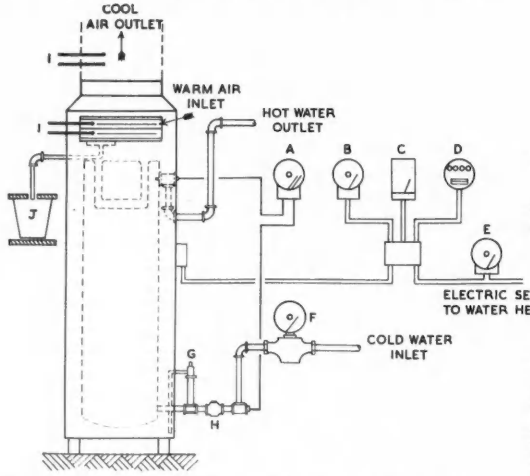


Fig. 1. **Diagram of arrangement of instruments for obtaining performance data on field test of electric heat-pump water heaters.**

(A) 2-pen recording thermometer ; (B) graphic demand meter, 30-min. interval ; (C) graphic Wh meter ; (D) ordinary Wh meter ; (E) graphic demand meter, 30-min. interval, to be provided for total domestic load, including water heater ; (F) water meter with recording chart ; (G) pressure relief valve ; (H) check valve ; (I) thermometer, dry bulb and wet bulb, or portable psychrometer; (J) pail for condensate from air heat source coil.

shows a cross-section of the heater unit. From this it will be seen that there is no external equipment section. The compressor and fan motor are hermetically enclosed in the upper section of the unit, with the compressor located so that the recessed-top storage tank forms a shell round it. Much of the normal heat loss from the motor is thus used to advantage. The compressor is driven by a $\frac{1}{3}$-hp motor, which, however, may be replaced by a $\frac{1}{2}$-hp motor and a correspondingly larger compressor, if required.

An unusual and desirable characteristic of the unit is the dehumidification effect of the evaporator coil. All the installations were reported to show a noticeable dehumidification effect. In one case, during two weeks of operation, 10 gallons of condensate were collected.

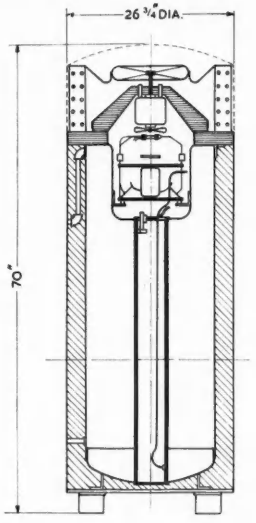


Fig. 2. **Schematic diagram of heat pump water heater.**

Fig. 3 is a graphic representation of test results obtained with eighteen installations, indicating how the average daily consumption of hot water affects the

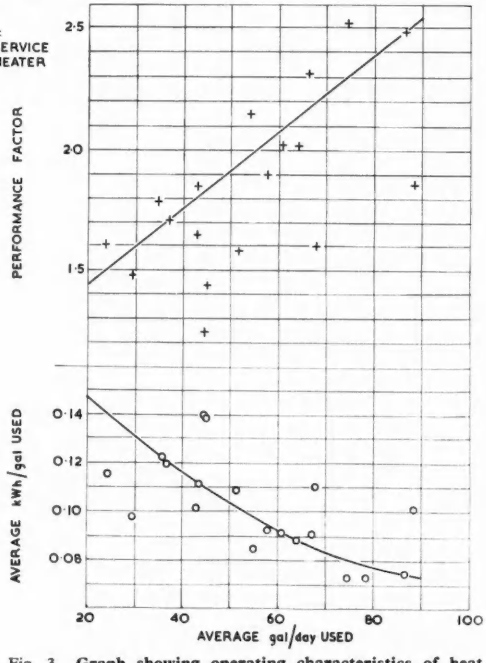


Fig. 3. **Graph showing operating characteristics of heat pump water heater based on operating data of pilot model installations.**

performance of this type of heat pump water heater. From the graph it may be seen that there is a relatively wide dispersion of test points. A possible cause of this dispersion is the variation of temperature differentials between the average inlet and outlet water temperatures. The inlet water temperature ranged from 50° F to 70° F, while the average outlet temperature during draw-off periods ranged from 127° F to 149° F. This inlet-outlet water temperature differential, for the installations under investigation, ranged from 60 to 90° F.

All the installations had short operating periods in the early morning hours in order to overcome standby losses and maintain the tank temperature as required by the respective thermostat settings. Since the standby losses are included in the total power consumption, the calculated performance factor is adversely affected. As it is intended here to present an indication of the normal overall operating characteristics of this specific unit, the standby losses have not been segregated.

(*Concluded on page* 30)

GERMANY

Rolling of Strip from Iron Powder

By G. NAESER and F. ZIRM. (From *Stahl und Eisen*, Vol. 70, No. 22, October 26, 1950, pp. 995-1004, 19 illustrations.)

Pulverised iron or steel piled up between two horizontal rolls is compressed and forced through the rolling gap by friction. The emerging coherent strip is sintered. The density and mechanical properties can be further improved by repeated rolling and annealing. The influence of process variables and the qualities of the final strip are investigated.

A FUNDAMENTAL disadvantage of present-day manufacture based on powder metallurgy principles is the limitation in size and shape of the products. However, during investigations of the properties of the German RZ-type iron powder,*[1] a very simple method of continuous rolling direct from the powder was found to be surprisingly successful. Although the cost of the powder imposes economic limits on the application of this process, it may become important for the manufacture of special metal products, such as magnetic iron sheet, porous metal strip, and alloy strip which cannot be cast.

A. ROLLING OF THE IRON POWDER

The test rolls were $4\frac{3}{4}$ in. wide, $2\frac{3}{4}$ in. in diameter, and driven at 24 rpm by a 3-hp motor. For a few tests, larger rolls of 8 and 36 in. diameter were also used. The majority of tests was undertaken on RZ-powder of the normal mesh size, since this material was most suitable for the process and gave products of the best mechanical properties.

Table 1. CHARACTERISTIC DATA FOR RZ-POWDER OF NORMAL MESH.

	C	Mn	P	S	O_2	Content
Analysis	0·03	0·19	0·028	0·017	0·30	per cent
Particle size	Above 0·012	0·006 to 0·012	0·0025 to 0·006	Below 0·0025		inch linear dimension
	1·5	34·8	49·0	14·2		per cent

Normal packing : 11·2 cu in. per lb.

Normal density : 31·7% of solid iron sheet

A uniform powder feed into the rolls is very important. The rolls are therefore arranged side by side along horizontal axes. A feed hopper, with a slot of the same length as the rolling gap, and arranged just above the latter, drops the powder onto the rolls. If the gap between the rolls is narrower than a certain critical width, the rolls draw the powder into the gap by friction, taking just the quantity of powder needed for the strip to emerge with uniform thickness and density (see Figs. 1 and 11). The feed of powder from the hopper need not be controlled, provided a sufficient quantity of powder is always available on top of the rolls (Fig. 1). Baffles prevent the spilling of powder over the ends of the rolls. As the powder is drawn into the gap, the particles are pressed together, interlock, and undergo plastic deformation. Calculation shows that at about 8 degrees above the gap centre (Fig. 1), the particles are already highly compressed, so that a strip of e.g. 0·018 in. final thickness then has a density of 2·26 lb per cu in., i.e., a specific density of 6·25, or 80 per cent of that of the solid iron sheet.

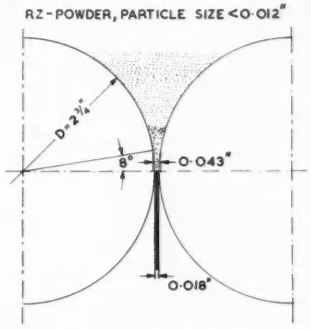


Fig. 1. **Deformation in the rolling gap.**

The general principles of, and experience gained with, powder metallurgy[2] can largely be applied to the rolling of metal powders and, together with preliminary tests undertaken, suggest that the manufacture and properties of soft iron sheet are mainly dependent on shape and mesh size of the powder particles, width of rolling gap, diameter of rolls, number of rolling passes and amount of deformation in each pass, speed of rolls, and perhaps the power reserve of the driving motor. If we work with given rolls and constant rolling speed, using the same powder throughout, and alter the *gap between rolls*, the thickness of the emerging strip will change as shown in Fig. 2. The maximum thickness obtainable is limited by the requirement that the strip must just be strong enough for transport into the sintering furnace, and the minimum thickness by the springiness of the rolls when they are in contact, i.e., by the characteristics of the rolling mill. With a decreasing rolling gap, the density of the strip and the rolling power required (Fig. 2) increase linearly at first : the space taken up by cavities becomes smaller, since the particles are pressed together more closely. Below a certain critical gap width, however, (about

*RZ-powder is produced by atomisation of liquid Fe-C alloys, with controlled partial oxidation so chosen that, on subsequent annealing at 950° C, the carbon and the oxygen are removed from the metal as far as possible, the CO and CO_2 gases providing a reducing atmosphere. The resulting particles are porous, with a low-carbon metallic zone and a spongy skin left by the reduction of the oxides.

0·0028 in. for the powder used), density and power increase much more steeply : the compressed particles undergo plastic deformation. The density finally almost reaches the value of normal soft iron sheet. The thickness of the emerging strip first decreases slowly as the rolling gap is reduced, then decreases more rapidly below the critical gap width.

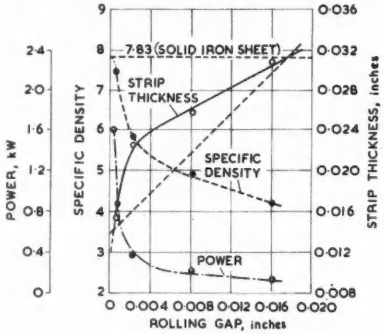


Fig. 2. **Strip thickness and density, and power required for rolling of RZ-powder, as functions of the rolling gap width.**

The *pressure* exerted by the rolls could not be measured directly. If, however, we take the density of the product as a measure of the pressure exerted, whether by rolling or die-pressing, then we may estimate the rolling pressure by comparison with the die pressure used for similar articles made from the same powder (Fig. 3). The more rapid increase of pressures attained below the critical gap width (at about 70 per cent density) is recognisable, and even the relatively light test rolls are seen to be capable of exerting pressures up to 38 tsi. The logarithmic graph Fig. 3 shows a straight, comparatively steep, line over the whole range of densities, this being an indication of a more uniform behaviour and higher deformability of the powder as regards rolling than are found for die-pressing.[3]

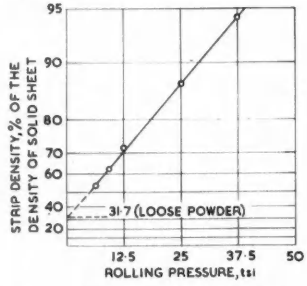


Fig. 3. **The logarithm of the density as a function of the rolling pressure for RZ-powder.**

The test rolls permitted production of rolled strip of 0·014 to about 0·030 inch thickness, the finished strip being 0·010 to 0·014 inch in thickness, a rather restricted range. Thinner strip, however, would hardly be economical, and thicker strip would require larger *roll diameters*, as shown by Fig. 4, which compares the resulting thicknesses of strip of equal density rolled on larger mills. In spite of unavoidable inaccuracies of evaluation, indicated by the shaded band, the general tendencies and orders of magnitude involved are obvious. Later tests on commercial rolling mills have also shown that thicker strip of higher density can be obtained if higher *rolling speeds* are used : the tensile strength of the unsintered strip was increased four- to fivefold. Above a certain speed, however, depending on roll

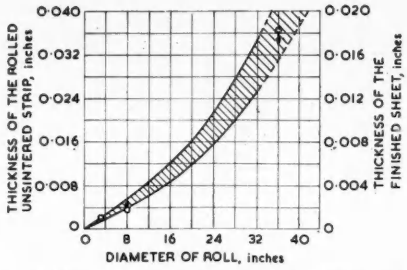


Fig. 4. **Thickness of comparable unsintered strip of RZ-powder rolled with different roll diameters. Specific density of strips 5·55 to 5·84.**

diameter and gap width, a coherent band no longer emerges, as the powder cannot be fed into the rolls quickly enough. The test set-up did not permit a thorough investigation. The *particle size* of the powder again influences the maximum obtainable thickness as well as the quality of the finished strip. If the powder is below a certain particle size, depending on the gap width, it flows through the gap without being compressed With normal gap widths and commercial powders, however, the influence of particle size on the strip thickness is only small. Very thin strip is best obtained with relatively fine-grained, and thick strip with a mixed commercial powder (particles of 0·012 in. linear dimension and less), which generally gives the best results. An entirely coarse-grained powder having no particles below 0·0025 inch size does not prove entirely satisfactory. The *surfaces of the rolls* may be highly polished or roughened, but must not be humid or covered by oil films if non-uniform brittle strip is to be avoided.

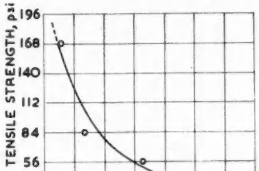


Fig. 5. **Tensile strength of the rolled strip as a function of rolling gap width.**

As the density decreases with an increasing rolling gap, so does the strength of the unsintered strip (Fig. 5). A strength of 28 psi is just sufficient for transport into the sintering furnace. Since rolling and die pressures required for equal product density are of the same order of magnitude in spite of process differences (linear zones of increasing pressures and one direction of free flow, as against equal pressures on planes of the enclosed die-form), we may conclude that the two processes require similar qualities in the initial metal powder. Hence, the widely varying rolling power required, and the tensile strength of the rolled strip, might well be used as simple and sensitive criteria of the powder-metallurgical qualities of different metals and mixtures.

B. SINTERING

A die-pressed strip is appreciably stronger after sintering at 1050 to 1100° C in a hydrogen stream. For a continuous rolling process, however, the sintering time must be much shorter than usual. Since experience on short-time sintering was not available, the influence of time and temperature had to be investigated. Thin strip, about 4¾ in. long and 0·8 in. wide, was annealed for short periods at 950, 1100, or 1200° C in

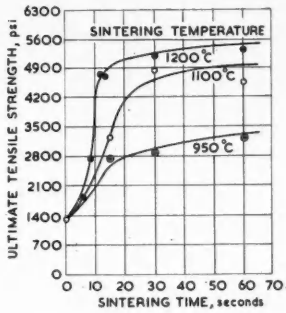


Fig. 6. **Tensile strength of rolled RZ-powder as a function of the sintering time.**

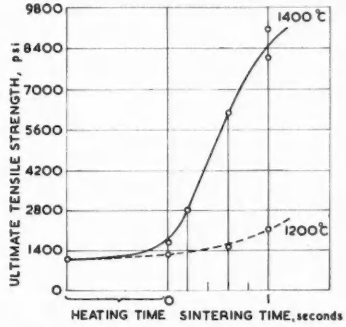


Fig. 7. **Tensile strength of rolled strips of RZ-powder after very brief sintering by direct electric resistance heating.**

a crucible under a hydrogen current, and cooled in another crucible in a nitrogen atmosphere. The resulting increase in strength (Fig. 6) is very appreciable at first and depends largely on the sintering temperature. After about 20 seconds, the strength increases more slowly. A tensile value of 3500 psi is reached after 10 seconds at 1200° C, but only after, say, 100 seconds at 950° C. Fig. 6 also shows three stages of the sintering process, confirming the results of theoretical investigations[4]: (a) the specimen reaches annealing temperature after a few seconds, (b) the compressed particles then weld together so that the strength curve suddenly steepens, (c) surface tension effects now increase the size of the welded surface area more slowly.

Still shorter sintering times at yet higher temperatures were investigated on strip of $\frac{3}{8}$ in. width. D.C. current from a battery was passed directly through the specimen held in a protective atmosphere, the heating speed being controlled by an adjustable series resistance. The light emitted by the heated specimen was focussed on to a photocell, and the detecting current amplified and recorded by a cathode-ray tube with time sweep. The cathode ray deflection was calibrated by comparison with a filament pyrometer. Fig. 7 indicates that the specimen reaches sintering temperature in about 1 second and that at 1400° C the sintering action is instantaneous. Tensile values of 8500 psi are already reached after 1 second at 1400° C. It thus appears economical to use very high sintering temperatures and short periods, i.e. short continuous furnaces. Narrow strip of highly alloyed steels may, in special cases, be heated directly by electric current passing through the two rolling mills, one arranged in front of and the other behind the sintering furnace. The reduction in volume during sintering is quite generally small for RZ-powders, in contrast to metal powders won by ordinary chemical or mechanical pulverisation.

C. SUBSEQUENT TREATMENT

Die-pressed and sintered iron products, unless required to be porous, are often pressed and sintered once again for higher strength and ductility. Strip rolled from iron powder must be compressed and sintered several times if the qualities of the solid rolled sheet are to be attained. Only products intended to be porous need no after-treatment. In these additional rolling passes, the amount of reduction is limited by the danger of transverse cracks. With the rather small test rolls, the sintered strip (0·018 to 0·022 in. thick) could only be reduced by 30 per cent in the first passes, and by 10 to 20 per cent in subsequent passes, even if annealed after each pass. After the fourth pass, the finished strip can be cold-rolled like ordinary iron sheet. Figs. 8 to 10 give characteristic data for the complete process and the changes occurring in the strip. The space still occupied by cavities after sintering is reduced very quickly, the thickness decreases first quickly, then more slowly, and the density approaches the value of solid sheet asymptotically, practically reaching it after the fourth pass. The specimens, 16 in. long, 4 in. wide, are annealed after each pass in a hydrogen current passed through a muffle furnace, and then cooled in a water-cooled section of the same furnace.

The tensile strength after annealing (Fig. 9) first

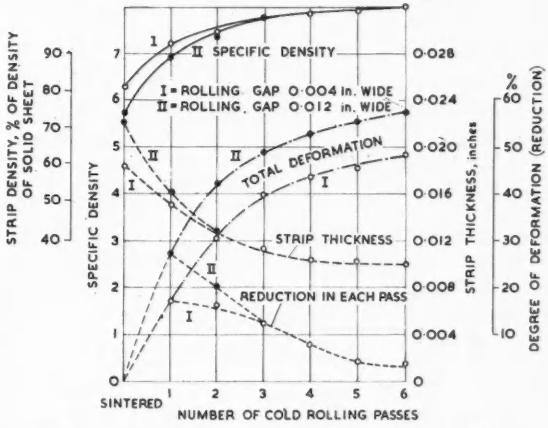

STRIP DENSITY, % OF DENSITY OF SOLID SHEET
SPECIFIC DENSITY
II SPECIFIC DENSITY
I = ROLLING GAP 0·004 in. WIDE
II = ROLLING GAP 0·012 in. WIDE
TOTAL DEFORMATION
STRIP THICKNESS
REDUCTION IN EACH PASS
STRIP THICKNESS, inches
DEGREE OF DEFORMATION (REDUCTION)
SINTERED
NUMBER OF COLD ROLLING PASSES

Fig. 8. **Change of density, strip thickness, and total deformation, with the number of rolling passes for RZ-powder. Annealing treatment after each rolling pass.**

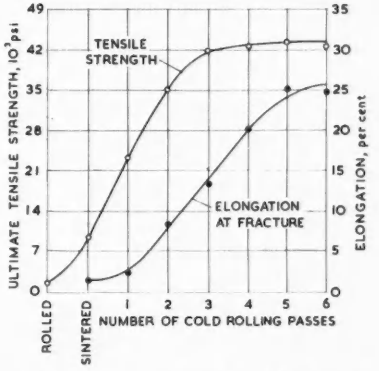


Fig. 9. **Change of tensile strength and elongation with increasing deformation. Specimens of RZ-powder tested after annealing for 1 minute at 1200° C. Elongation measured over gauge length of 0·8 inch.**

increases with increasing density, but in the later stages the metallic part of the cross-section also gains in strength, probably because of crystallisation phenomena. Whilst the strength remains practically constant after the third pass, the tensile elongation still increases appreciably up to the fifth pass. Three passes are thus sufficient for good strength, but five passes are required for high ductility. The annealing treatment after the first rolling pass of the sintered strip still increases its strength, due to a sintering action (Fig. 10). With the second pass there begins the well known interplay of work hardening with subsequent softening by annealing treatment. Powder-metallurgical products are inclined to severe grain growth at temperatures above 850° C. Since this growth is especially dangerous for thin sheet, the cold rolled strip is finally annealed at a lower temperature (about 650° C). The influence of the powder particle size and distribution largely disappears after repeated rolling. The usual strength of solid sheet is reached after the third pass (Figs. 9 and 10). Deep drawing results obtained with the final strip complied with the standards prescribed for similar solid sheet. Repeated bending tests showed excellent results and folding tests still showed satisfactory results as compared with solid sheet.

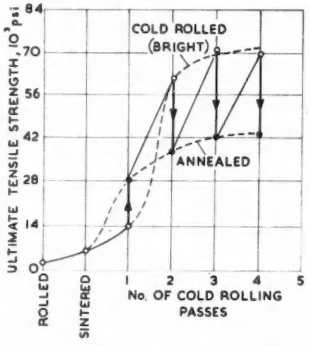


Fig. 10. **Changes in tensile strength after cold-rolling and after subsequent annealing, during the after-treatment of strip of RZ-powder.**

A powder-metallurgical product can be intensively densified by hot pressing above 900° C.[5] Hot rolling after, or even before, sintering may therefore appreciably improve the final mechanical qualities as well as shorten the entire process. Although systematic tests were not undertaken, one strip pressed from powder (0·35 in. thick, 5·55 specific density) was hot-rolled on 36-in. rolls, with a reduction of 43 per cent. It thus obtained a specific density of 7·45, or 95 per cent of the solid sheet and, on test, fractured with 14 per cent elongation (2 per cent after cold-rolling).

The investigations reported here may provide the basis for a commercial continuous strip rolling process as shown schematically in Fig. 11.

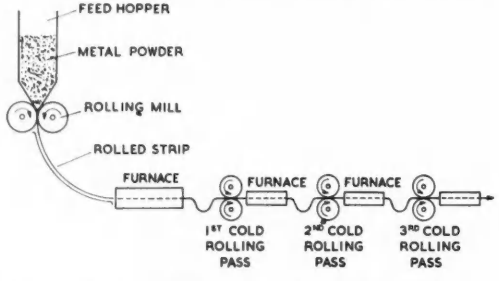


Fig. 11. **Continuous rolling process for strip produced from metal powder.**

D. SPECIAL MATERIALS

Steel strip of higher tensile strength can be produced by rolling of either steel powders or mixtures of iron powder with carbon carriers. The simplest and most satisfactory process, however, especially for thin strip, is carburisation of iron strip in suitable gases ; a fairly high carbon content is obtained in a very short time (Fig. 12). Examination of a specimen carburised in town gas for 1 minute at 1200° C showed 1·33 per cent carbon and a normal cementation structure with complete lack of porosity. In contrast to electrolytic or carbonised iron powders, RZ-powders generally develop a normal carburised structure. Sintering in a carbon-rich atmosphere should, therefore, make possible the continuous rolling of steel strip from powder, provided a suitable gas mixture is found for sufficient carburisation in the short time available.

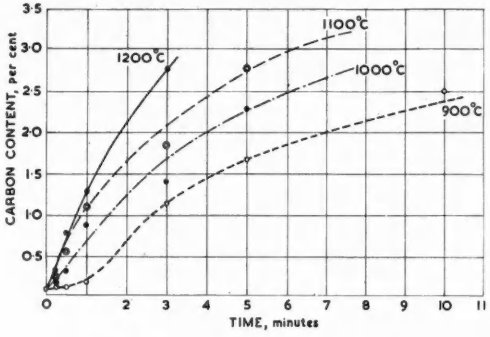


Fig. 12. **Speed of carburising sintered iron sheet, 0·002 in. thick, in town gas with benzol vapours as protective gas.**

Special powder feeding arrangements may permit manufacture of strip with layers of chemically different materials. A *compound strip*, with 2 per cent C-steel at the centre and soft iron on the outside, was in fact rolled successfully. The short sintering times would prevent any appreciable diffusion of the carbon from the centre, and protective atmospheres may further prevent decarburisation. Compound sheets of this type may be useful for the manufacture of self-sharpening knives. *Highly alloyed metals* offer some difficulty in sintering, since the chromium and aluminium oxides cannot be reduced in hydrogen. Direct electric heating to very high temperatures and, perhaps, hot-rolling in a protective atmosphere may overcome these difficulties. Alloys which cannot normally be rolled from the cast state may well be produced by this method.

The powder-metallurgical rolling process offers special advantages for the production of *magnetic soft iron sheet* from electrolytic iron powder improved in magnetic qualities by suitable alloying additions and decarburisation in hydrogen. *Bronze powders* could be rolled successfully. Obviously, the rolling gap must be adjusted to suit the different metal powders.

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Quantitative Measurement of Detonation Intensity in Internal Combustion Engines

By G. E. V. JONSSON. (From *Acta Polytechnica*, 1950, No. 62, Mechanical Engineering Series, Vol. 1, No. 10, 30 pages, 20 illustrations.)

This article describes a new method for the determination of the detonation intensity in internal combustion engines, based on rate-of-pressure-rise measurements made with a new type of pick-up insensitive to mechanical vibrations. Details of the pick-up and the associated electronic circuit, as well as of test results, are also given in this report which is the result of an investigation of the combustion process in internal combustion engines carried out at the Engine Laboratory of the Research Station of the Royal Swedish Academy of Engineering Sciences.

SOME OBSERVATIONS ON INTENSITY MEASUREMENT

The nature of the detonation phenomenon is now fairly well known. In the initial stages of the burning, both the speed of the flame front and the rate of pressure rise are similar to those under non-detonating conditions. Towards the end of the flame travel there is, however, a sudden change in the flame movement indicating an abnormally high rate of ignition of the remaining portion of the charge. Rapid combustion in front of the flame gives rise to high local pressures and high-frequency pressure waves which are reflected across the combustion chamber at sonic velocity. These sudden pressure variations are transmitted to the cylinder walls which vibrate and generate audible sound waves.

Detonation must be clearly distinguished from phenomena with somewhat similar manifestations which are the result of hot-spot ignition somewhere in the combustion chamber. A hot spot on an exhaust valve, for instance, may cause ignition after passage of the spark and produce a new flame with accelerated flame speed and pressure rise, not necessarily accompanied by detonation. Hot-spot ignition may also occur before passage of the spark and this case is more easily detected.

Quantitative measurements of detonation intensity must be carried out, therefore, in such a way that they will not be influenced by increased rates of pressure rise caused by hot-spot ignition, increased compression ratios or charging pressures.

THE dp/dt OSCILLOGRAM

In this investigation, recordings have mainly been made of the rate of change of pressure as a function of the crank angle. Typical recordings of non-detonating and detonating combustion conditions are shown in the photographs of Fig. 1.

A cursory examination of these photographs may give the impression that detonation involves a progressive increase in the maximum rate of pressure rise during combustion. The diagram on an expanded time base, Fig. 1c, however, shows the details of the process, and it is clearly apparent that the normal phase of the combustion reaches its maximum rate of pressure rise before detonation sets in. Incipient detonation occurs after the point *A*, corresponding to zero rate of pressure-change and hence to maximum pressure. Although combustion is not quite completed at this point, the positive rate of change due to combustion is counteracted by a negative rate caused by the descending piston, so that the resultant recorded rate of change is nil. The first signs of detonation thus appear at a point *B*, where the rate of change of pressure is decreasing towards negative values, but where the combustion is still not completed. No audible detonation is produced at this stage. The portion of the fuel-air mixture which is spontaneously burning ahead of the flame front is small, and the detonation wave generated has a small peak amplitude and is soon damped out. The earlier the normal flame propagation is disturbed by rapidly-detonating combustion ahead of the flame front, the further point *B* will be shifted in the direction towards point *C*, where the normal phase of the combustion has its maximum rate of pressure rise.

However, even with severe detonation, the point *B* at which detonation commences will be situated at a considerable distance from point *C*, on the portion of the curve where the rate of pressure-change due to normal combustion is decreasing.

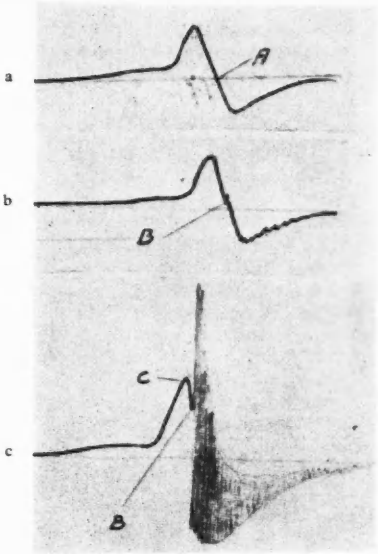

Fig. 1. Rate of change of pressure diagram.
(a) non-detonating; (b) incipient knock (point *B*) not audible; (c) detonating, heavy knock.

In the case of incipient detonation, the maximum dp/dt-value of the detonation wave is small relatively to that of the normal combustion phase. Detonation is already quite audible when the two values are of the same order of magnitude. Whereas the rate of pressure change of normal combustion depends on the operating conditions and increases with higher compression ratios, charging pressures and mixture temperatures, varying probably also with the type of fuel used, the rate of pressure change of detonation is largely a function of the reaction velocity and the quantity of fuel-air mixture reacting in the detonating phase. Consequently, a comparison of the maximum dp/dt values of non-detonating and detonating combustion will not give a satisfactory result.

The measurements of detonation intensity should therefore be based on a consideration of the entire damped pressure wave. The maximum amplitude of the detonation wave increases according to the amount

of fuel-air mixture which burns spontaneously ahead of the flame front. The damping is more or less rapid and appears to be related in some way to operating conditions, such as the pressure and temperature of the gases, and the type of fuel employed. Tests with closed vessels indicate that reaction continues for some time behind the shallow flame front, and it is possible that the amplitude of the reflected pressure waves is affected by the reactions set up by the passage of the pressure waves through the gas.

It would seem, therefore, that the measurements should cover the entire damped pressure wave, and the present investigation is based on the measurement of the first differential of pressure, since this offers the greatest possibilities for the determination of detonation intensity.

PRINCIPLE USED FOR RECORDING THE RATE OF CHANGE OF PRESSURE

The rate of change of pressure may be indicated by various means and previous investigators have used mainly electromagnetic pick-ups for this purpose. The author first made use of a Zeiss Ikon engine indicator with a piezo-electric pick-up and d.c. amplifier, coupled to a differentiating circuit. In view of the trouble occurring with d.c. amplification, the author suggested in 1941 the use of a piezo-electric device with a voltage output proportional to the rate of pressure change and permitting the use of an a.c. amplifier of more simple design.

The principle employed is as follows :—When a quartz crystal is subjected to a pressure of p [dynes/cm^2] in the direction of its electric axis, an electric charge q [coulombs] is developed on its surface. Thus,

$$dH = H\,dp \quad \text{or} \quad H = \partial q/\partial p \qquad .. \quad (1)$$

H is known as the piezo-electric constant, and its value for quartz is $H = 21 \times 10^{-18}$ [coulomb cm^2/dyne]. The rate of pressure is then given by

$$dq/dt = (\partial q/\partial p)\,dp/dt = H\,dp/dt \qquad .. \quad (1')$$

and furthermore, $q = Hp$, which indicates that the total charge accumulated on the crystal at any instant is proportional to the applied pressure. Pressure measurement requires, therefore, an integration of the rate of change of the charge and, in order to prevent the charge from flowing away, an insulation resistance of the order of 10^6 megohms. This high insulation resistance must be present between the grid and earth of the input valve of the d.c. amplifier. This type of amplifier is, however, very sensitive to disturbances, so that an electrical differentiating circuit behind the amplifier will not give adequate results.

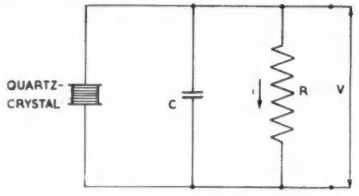

Fig. 2. **Piezo-electric crystal shunted by capacitance and resistance.**
Output voltage proportional to applied pressure p if $\omega RC \gg 1$, and proportional to dp/dt if $\omega RC \ll 1$.

Nevertheless, the first differential of pressure may be obtained by means of the circuit shown in Fig. 2. The quartz crystal is connected to a shunt resistance R. In parallel with this is the capacitance C, which is constituted by the low capacitance of the crystal itself and the distributed capacitance of the cable connecting the crystal to the amplifier. Then, if q = charge developed on the crystal, q_C = charge accumulated on the condenser C, and q_R = charge flowing away through the resistor R, at any instant

$$dq/dt = dq_C/dt + dq_R\,dt \qquad .. \qquad .. \quad (2)$$

The voltage across the condenser is $V = (1/C)\int dq_C$ and therefore $dV/dt = dq_C/(C dt)$, so that $dq_C/dt = C dv/dt$. This voltage is also applied across the resistor R, and the current flowing through it is $i = dq_R/dt = V/R$. Substituting these results in eq. (2) and using eq. (1′) we obtain :

$$H dp/dt = C dV/dt + V/R \qquad .. \quad (3)$$

If $p = p_0 \sin \omega t$ and $dp/dt = \omega p_0 \cos \omega t$, eq. (3) becomes

$$C\frac{dV}{dt} + \frac{V}{R} = Hp_0\,\omega \cos \omega t \qquad .. \quad (4)$$

and its solution is

$$V = RHp_0\,\omega\,[\cos \omega t + \omega RC \sin \omega t - e^{-t/(RC)}]/[1 + (\omega RC)^2] \qquad .. \qquad .. \quad (5)$$

The circuit will indicate the rate of change of pressure if $\omega RC \ll 1$, since in this case $V = RHp_0\,\omega \cos \omega t = RH dp/dt$. The crystal capacitance is only about 10 pF so that C represents mainly the cable capacitance. The time constant RC should not exceed 5×10^{-6} second for correct response up to 10,000 cps. If the total capacitance C is 100 pF, the required value for R is 50,000 ohms.

If $\omega RC \gg 1$, the circuit will indicate the pressure amplitude, since in this case the sine-term will predominate in eq. (5) with the result that $V = (Hp_0/C) \sin \omega t$ or $V = (H/C)\,p$. The output voltage is then proportional to the pressure p acting on the crystal. To obtain a high RC-value, an additional condenser of 2 to 4 μF is required in parallel with the crystal, and the resistance R must be approximately of 2 megohms. The time constant will then be sufficiently low to give correct pressure indication even at comparatively low engine speeds.

In both the cases just mentioned, an a.c. amplifier may be employed. The above method has been used by the author since 1941 for tests with substitute fuels on hot-bulb engines and in detonation research.*

DESIGN OF THE PICK-UP

To ensure correct response, the pick-up must have a natural frequency at least 5 to 6 times greater than that of the detonation pulses. Furthermore, it should be insensitive to mechanical vibrations occurring in the engine, since these are in the same range of frequencies as detonation. A survey of the types of pick-up commercially available and of the methods evolved by various investigators for eliminating vibrations showed that, for various reasons, they could not be applied in the present case.

The problem was therefore subjected to closer investigation. C. Allander proposed that the piezo-electric crystal be placed between two diaphragms in such a way that both diaphragms would be acted upon by the gas pressure as illustrated in Fig. 3. The tests showed promising results. Although the pick-up had a natural frequency not exceeding 30,000 cps, its sensitivity to mechanical vibrations was reduced to a fraction of that of pick-ups of the single-diaphragm type. The small amount of mechanical vibration still apparent was due to the fitting of the crystals between the diaphragms, which allowed a certain amount of sliding to occur between the crystal surfaces, particularly when the vibrations acted at right angles to the electrical axis of the crystals. How-

*R. Marchal in " Moteurs d'avions," Dunod, Paris, 1946, mentions that the same method for the measurement of dp/dt had been suggested, but not yet applied, by Pérot.

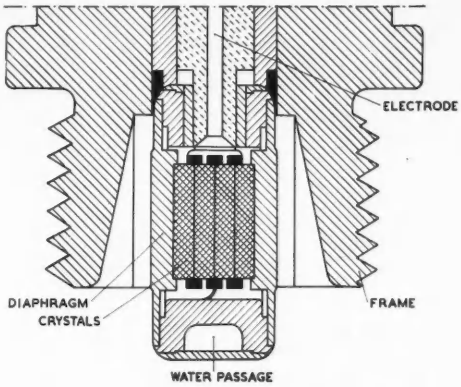

Fig. 3. **Sectional view of an improved piezo-electric pick-up.** The crystals are arranged between two diaphragms, both of which are acted upon by the pressure. The pick-up has a standard $\frac{7}{8}$ in. sparking plug thread.

ever, even with the first pick-up developed, the effect of mechanical vibrations was negligibly small in detonation measurements.

A second pick-up of modified design had a higher natural frequency of 42,500 cps and a still lower response to external vibration. It appears that it may be possible to develop pick-ups of this type with a much higher natural frequency, probably reaching up to 100,000 cps, which, by many investigators, is considered to be desirable for the correct recording of detonation.

A theoretical investigation was also made of the conditions which had to be fulfilled for the correct measurement of the high-frequency pulses associated with detonation. It has been found that a high natural frequency of the pick-up is not in itself sufficient to ensure correct response to detonation waves, which are non-stationary and non-periodic. This may be explained by the following example :—If we consider two pick-ups, both with the same natural frequency, but one having double the spring constant and mass of the other, then the pick-up with the smaller mass will have greater sensitivity and give the more accurate response.

Therefore, the natural frequency to be considered is that of the complete vibrating system and not that of the crystal alone, which usually exceeds 1 million cps. The two-diaphragm pick-up shown in Fig. 3 had a vibrating mass of only 3·5 grammes and a natural frequency of 33,000 cps, whereas the piezo-electric pick-ups commercially available have a moving mass of 25 grammes and a frequency of the order of 25,000 cps.

THE DETONATION METER CIRCUIT

The output voltage of the pick-up, which is proportional to the rate of change of pressure, is amplified in an a.c. amplifier unit, and the trace of the combustion cycle is indicated on the screen of an oscillograph connected to the amplifier.

A simplified diagram of the detonation meter circuit is given in Fig. 4. The output of the monitoring oscillograph amplifier stages is fed through an impedance transformer *a* into a high-pass filter *b* with a low input impedance and responding to frequencies between 3,000 and 9,000 cps. This filter is used to eliminate the fundamental frequency of the dp/dt pulses corresponding to the compression and expansion cycles and also gives a sharp cut-off between the detonation and the normal combustion frequencies. The filter is followed by a further amplification stage *c* and the amplified output is rectified in a triode *d*. The filtered and rectified voltage is thus the positive half of the first differential of the pressure pulses occurring during detonation. This voltage is then integrated in an *RC* circuit *e*, and provided the value of the time constant is sufficiently large, the voltage across the condenser will be proportional to the mean value of the amplitude of the detonation pulses. The voltage across the condenser is then measured by a bridge-coupled valve voltmeter *f* and indicated by a milliammeter *M*.

The various difficulties arising in the development of the electronic circuits were gradually overcome. Zero-drift was eliminated and the linearity of the response was checked by means of calibrations with a special oscillator unit giving high-frequency voltage pulses having the same frequency and duration as the detonation pulses in the engine. Adequate stability and reproducibility of the readings were also obtained.

MEASUREMENT OF THE DETONATION INTENSITY

As, unfortunately, the detonation intensity varies from cycle to cycle, the measurement must be extended over a large number of cycles, and this is obtained by using a high time constant in the *RC* circuit. The meter reading is, therefore, an arithmetic mean which is a function of both the intensity and the frequency of occurrence of detonation. The readings are thus also proportional to the engine speed if the detonation intensity and frequency of occurrence per engine cycle are unchanged. However, the results can easily be compared by reducing the readings to the same engine speed.

The meter readings will also indicate the difference in damping of two detonation waves having the same peak amplitudes but produced by different fuels.

Fatigue failures due to detonation are not caused only by isolated detonations giving large-amplitude pressure pulses, but also by more or less constantly recurring detonation pulses of relatively small amplitude. It seems to the author that detonation is not so spasmodic in nature as it would appear when evaluations are made by the ear, which can only detect detonation over a limited range of frequencies. This also applies to evaluations based on counts of the number of detonations exceeding a given value for the peak amplitude. Although large differences are occasionally observed in the maximum amplitudes of detonation in consecutive cycles, these variations are not, in the author's opinion, associated with the nature of the detonation, but seem to be due, to some extent, to fluctuations of the fuel-air ratio and other factors affecting the combustion.

In the engine used for the tests, the author observed appreciable differences in the combustion in con-

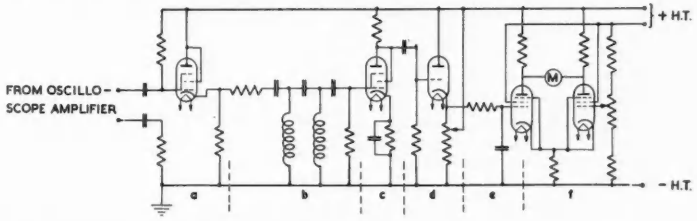

Fig. 4. **Basic circuit of detonation meter.**

secutive cycles, and these caused fluctuations of ± 20 rpm in the engine speed. The engine was therefore stripped and rebuilt, and instead of the carburetter an electromagnetically-controlled injection nozzle was used for accurate control of the quantity of fuel injected. Subsequent tests showed a marked stabilisation of the combustion, and as a result the speed fluctuation was reduced to less than ± 2 rpm, although the same flywheel was used as previously. The differences in the maximum amplitudes of the detonation pulses in consecutive cycles were also reduced. Although it would have been possible to control the speed externally by coupling the engine to a synchronous generator, this would not have eliminated the fluctuations in the combustion or their various causes.

(To be continued.)

HOLLAND

Time-Measurements using the Joergensen-Weibel System

By J. H. P. Koot. (From *De Ingenieur*, Vol. 62, No. 43, October 27, 1950, pp. O.39-O.43, 5 illustrations.)

The Joergensen-Weibel electronic chronograph was first used for the determination of the velocity of artillery projectiles. It is now also being employed to investigate the mechanical properties of materials, by determining the velocity of propagation of longitudinal sound waves in elastic materials, and correlating the value obtained for sonic velocity with the strength and type of structure of the material considered.

The time measurement is based on the discharge of a condenser, the basic principle being as shown in Fig. 1. The circuit consists of a battery (3) with a voltage V, a discharging resistance (4) of a known value of R ohms, a condenser (5) of C microfarads, a potential divider (6) of r ohms resistance, and a valve voltmeter (7), which measures voltages without acting as a load on the circuit. The contacts (1) and (2) are operated by relays, triggered by current pulses from coil, photocell or microphone type pick-ups connected to suitable amplifying equipment.

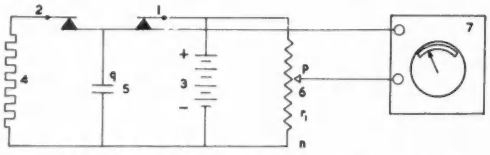

Fig. 1. **Basic diagram of time-measuring circuit.**

Before the measurement, both contacts are closed. A current then flows through (4), and the condenser is maintained at a potential V. The measuring period begins when contact (1) is opened, thus cutting out the battery and allowing current to flow through (4), as a result of the condenser discharge. At the end of the measuring period, contact (2) is opened. The condenser still has a potential v, which is determined by the relationship :

$$v(t) = V e^{-t/(RC)} \quad \text{[volts]}$$

where t is the time elapsed, in seconds.

Immediately before the measuring period, the potential divider (6) should be adjusted to a point p, so that the valve voltmeter will give a zero reading. This point then has the same potential as the point q. If r_1 is the resistance of the portion pn of the potential divider, which has a total resistance r, then we can write :

$$r_1/r = v/V = e^{-t/(RC)} \quad \text{or} \quad t = -RC \log_e (r_1/r).$$

This shows that the time t is fully determined by the values of C, R, r and r_1, all of which can be determined with great accuracy. By using the potential divider, the circuit is independent of the battery voltage, which never is absolutely constant.

A simplified circuit diagram of the measuring equipment is given in Fig. 2. The discharging resistance (4) is adjustable to cover the values of 5, 10, 20, 30, 45, 75, 100, 300, 1000 and 3000 kilo-ohms. The condenser (5) has a capacitance of the order of 1μF. A battery of 9 volts (3) is used in parallel with potential divider (6) with a two-stage adjustment, giving tenths and hundredths of the battery voltage. Before the beginning of the measurement, the two relay contacts R_1 and R_2 are closed. After the measurement the relay R_4 in the amplifier circuit connects the negative side of the condenser with the grid of the valve voltmeter.

The relays R_3 and R_4 also cut out the connection between the measuring condenser (5) and the relays R_1 and R_2, this being necessary in order to prevent any possibility of measuring errors which may result from a defective insulation of the relays. The contact relay R_3 is in parallel with the battery (3) so as to have the same load on the battery as before the measuring period.

The potential divider (6) gives the ratio r_1/r to two decimal places. In parallel with it and across the battery is a further voltage divider (7) supplying a voltage of 30 millivolts to the valve voltmeter. The cathode resistor (13) is adjusted so as to obtain a full scale deflection of the pointer of the milliammeter (15) with the 30 millivolts input. The value of r_1/r is found by means of the instrument indication and the adjustment of the decade resistor elements of the potential divider. This gives a further division into twelfths, and the 1/120ths can be estimated.

The valve voltmeter includes three valves (9), (10) and (11), and the milliammeter (15). The zero adjustment of the voltmeter is obtained by means of the potentiometers (14), controlling the grid voltage, and sensitivity is varied by means of the potentiometer (13). The valve voltmeter has the advantage that after the measurement the pointer of the instrument will remain at the same position for some time, and this makes it possible to determine r_1/r with sufficient accuracy. In 10 seconds the pointer does not normally move more than 1/10 of a division, which corresponds to a change in the time value of approximately 0·03 per cent.

The pick-up amplifiers are of identical construction, and each consists of an input transformer, a resistance-coupled pentode and a triggering circuit, arranged so that the anode current will increase suddenly when a certain negative threshold voltage is reached in the grid circuit. This anode current flow is independent of subsequent grid voltage variations, and sets in immediately after a positive impulse is received from the amplifier stage.

The pulse shape obtained with a coil type pick-up when a magnetised projectile is passing through the coil is shown in Fig. 3. The triggering circuit operates as soon as the pulse voltage has reached a small value y at a time x shortly after the zero instant, so that the pulse is very steep, and the value of the threshold voltage thus has very little effect on the time measurement.

The chronograph may be affected by measurement

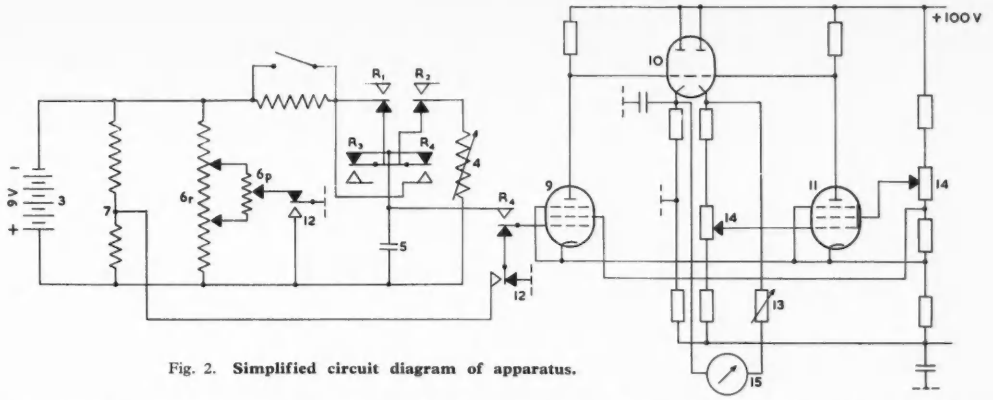

Fig. 2. **Simplified circuit diagram of apparatus.**

errors, which can be taken into account by means of a correction $\Delta f = \Delta r_1/r$ and which are due to the following causes :—(1) defective behaviour of the discharging resistance R or of the condenser C ; (2) faults due to residual charge of the condenser, undesirable capacitances and self-inductances, and losses in the network ; (3) temperature effects on the condenser and the resistors ; and (4) different time-lags in the operation of the two measuring relays.

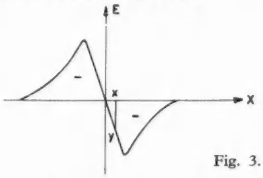

Fig. 3. **Shape of voltage pulse.**

Defects mentioned under (1) and (2) can always be avoided by periodic checking of the apparatus, for instance, once a month, against a calibrated time standard.

Defects mentioned under (3) mainly affect the condenser, since high-quality resistors are hardly affected by normal temperature variations. The specially designed condenser used for measurements has a temperature coefficient of 0·007 per cent per °C., and is calibrated to 0·5 microfarads at 15° C.

The difference in time lags of the measuring relays requires particular attention . This time-lag difference, denoted by T_0, is normally about ±15 microseconds, the normal amount of scatter in the response time of a single relay being 2 microseconds.

The corrections required to eliminate the errors (1), (3) and (4) from the measurement results can be calculated as follows :—

From r_1/r $\quad f = e^{-t/(RC)}$, where t and RC are variable, we have :

$$-\Delta f = f \log_e f \left\{ \Delta RC/(RC) \right\} + f T_0/(RC) = \Delta A + f T_0/(RC)$$

where T_0 is written for Δt. When $f = 0{\cdot}5$ we have $f \log_e f = 0{\cdot}35$. For other values of f, the values of $f \log_e f$ are tabulated below as percentages of $0{\cdot}35 = 0{\cdot}5 \log_e 0{\cdot}5$:

f ..	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
$f \log_e f$ %	60	93	104	106	100	89	72	52	28	0

Thus, for values of f between 0·2 and 0·6, the variation is not greater than 10 per cent. In practice, $\Delta A_{0{\cdot}5}$ is smaller than 0·0015.

The reading inaccuracy is approximately 0·0001, and if we put $f \log_e f$ equal to 0·35 in all cases, we make an error in the range $0{\cdot}2 < f < 0{\cdot}4$ which is of the same order of magnitude as the reading error. In practical cases, we can use as a very rough approximation the relationship

$$f = -0{\cdot}35\,(\Delta RC)/(RC) - 2f\,T_0/R = -\Delta A_{0{\cdot}5} - 2f\,T_0/R,$$

where $C = 0{\cdot}5\ \mu$F, T_0 being measured in milliseconds and R in kilo-ohms.

Example : A projectile is fired over two photocell pick-ups and the time of flight is to be determined.

The results are worked out as follows :— $R = 30{,}000$ ohms, $C = 0{\cdot}5\ \mu$F, $r = 0{\cdot}4$, p $= 0{\cdot}02$, milliammeter reading $= 17{\cdot}2$. Then

$$f' = 0{\cdot}4000 + 0{\cdot}0200 + 0{\cdot}0172 = 0{\cdot}4372,$$

$T_0 = 0{\cdot}015$ (test figure), and $0{\cdot}35\,(\Delta RC)/(RC) = 0{\cdot}0004$ (from calibration). Then $\Delta f = (0{\cdot}015/30) + 0{\cdot}0004 = 0{\cdot}0005 + 0{\cdot}0004 = 0{\cdot}0009$ and $f = f' + \Delta f = 0{\cdot}4372 + 0{\cdot}0009 = 0{\cdot}4381$. This value of f can be looked up in a table and the corresponding time is : $t = 12{\cdot}38$ milliseconds. Knowing the distance between the two photocell positions, the mean velocity of the projectile can be determined. The measurement range of the apparatus is approximately $0{\cdot}25 < f < 0{\cdot}65$.

The time standard used for calibration is of the falling weight type. A mass of lead is released pneumatically and allowed to fall freely, and breaks two contacts set at a known distance from each other in its path. The time t is determined by means of the equation

$$t = [\sqrt{2H_1} - \sqrt{2(H_1 - H_2)}] \Big/ \sqrt{g}$$

where g = local acceleration due to gravity, and H_1, H_2 = heights of contacts 1 and 2 below the plane of reference. The time standard can be connected to the chronograph in order to determine the $\Delta A_{0{\cdot}35}$ constant which figures in the correction Δf.

The time standard is adjusted to a known time interval and the chronograph measurement is normally slightly different. The two results will be denoted by f_t and f_m. The f_t value for the contacts is read off a corresponding table for the weight used, and the f_m value is based on the value of R, and may be affected by temperature. If Q is the temperature at which the measurement is taken, then

$$\Delta A_Q = -(f_m - f_t) - (2f\,T_0/R)$$

In this equation, R is in kilo-ohms and T_0 in milliseconds. As the temperature coefficient of the condenser is $-0{\cdot}007\%$ per °C, the value of ΔA_Q reduced to 15° C is

$$\Delta A_{15} = 0{\cdot}35\left[\frac{(\Delta RC)}{(RC)} + \left(\frac{(RC) - 0{\cdot}00007}{(RC)}\right)(15 - Q)\right]$$

or $\Delta A_{15} = \Delta A_Q + 0{\cdot}245 \times 10^{-4}(Q - 15)$.

If the temperature variation is less than 5° from 15° C, the temperature correction may be neglected and ΔA_Q used without the second term. The mean value of ΔA is then determined from several series of measurements with different R values. Each mean ΔA should be based on at least 5 measurements, and the values thus found should not show a scatter exceeding 0·0002.

Example : R = 70 kilo-ohms, f_t = 0·4994 (time standard), temperature = 24° C, T_0 = 0·017 millisec., f_m = 0·4986 (chronograph measurement). Then $A_{24} = -(0{\cdot}4986 - 0{\cdot}4994) - 2 \times 0{\cdot}499 \times 0{\cdot}017/70 = 0{\cdot}0006$. Reduced value : $A_{15} = 0{\cdot}0006 + 0{\cdot}35 \times 0{\cdot}00007 \times (24 - 15) = 0{\cdot}0008$.

For materials testing, the Joergensen-Weibel chronograph is used with quartz crystal pick-ups. It appears that the velocity of sound in longitudinal vibrations of a material may be regarded as a basis for the assessment of the strength of the structure of the material investigated. In this manner it is possible to check the strength of concrete underground chambers, bunkers, bridge constructions, etc. Further applications may be found in geological investigations.

FRANCE

A New Electrostatic High-Voltage Generator

By P. HEMARDINQUER. (From *Electricité*, Vol. 34, No. 165, October, 1950, pp. 254-256, 4 illustrations.)

THE development of electronic apparatus, and the rapidly widening fields of their application, require sources of electricity of very high voltage, which, however, only necessitate supply current intensities of the order of micro-amperes or, at most, milli-amperes. Sources of this kind are required, for instance, for the operation of electron-microscopes and electron-telescopes, cathode-ray oscilloscopes, television transmission and receiving tubes ; very high voltages and low current intensities are also required for electrostatic dust precipitators, the spraying of charged powders in agriculture, in electro-medical apparatus, etc.

The conventional sources of supply for such purposes are arrangements of transformers, condensers and rectifier valves connected to the a.c. supply mains. There are, however, a number of disadvantages connected with the use of such sources of high voltage supply, so that recently attention has again been drawn to the possibility of using electrostatic generators which previously had only been of interest in the laboratory.

The principle of the electrostatic generator is that of adding individual electric charges to a " collector." It thus consists of three basic parts : a source of electricity, which may be a friction arrangement, a charge conveyor and the collector. The electrostatic charge of the latter increases gradually, this accumulation of energy being equivalent to the energy used up by the conveyor system in transporting the charge taken from the source to the collector.

The best-known of these machines is the Wimshurst machine, consisting of two circular ebonite or glass discs arranged parallel and close to each other, and rotating in opposite directions on a common axis. These discs carry out the function of " conveyors," while the collectors are conducting points placed near the discs ; each disc forms an inductor with respect to the other. Metal brushes, connected to earth through resistances, slide over metal foil segments glued to the discs and thus initiate the generating process. The electricity produced charges two condensers.

These machines have so far been only of very restricted interest, as the electrostatic field cannot be increased above 30,000 volts/cm in air of atmospheric pressure without producing ionisation, which is detrimental to their operation. One method to overcome this limitation is to operate the machine in a gas under a pressure higher than atmospheric. However, experiments have shown that this increase of ambient pressure alone brought an improvement, but did not lead to the expected results, and a completely new design had to be developed for a high-voltage generator suitable for industrial applications.

It was found necessary to use thick plates, instead of very thin metal foil for the metal segments, and to operate the machine under high gas pressure. The new machines thus have metal plates 2 to 6 mm thick running in a gas-tight container under a pressure of 20 to 30 atmospheres. The intensity of the electrostatic field so far obtained is 1500 to 2000 e.s.u., and it is expected that 3000 e.s.u. will be reached with this design.

When operating under a gas pressure of 20 to 30 atmospheres which increases their initial capacity by a factor of the order of 200, these electrostatic generators can produce pressures of 10,000 to 200,000 volts, and intensities of 0·01 to 10 mA.

To maintain the high gas pressure required without risk of losses or explosion, it is necessary to use light alloys and carefully designed joints of elastic material. The problem of electrical insulation must also be carefully considered, as it is necessary to provide for permanent differences of potential of more than 100,000 volts.

As the volume of these machines is proportionate to their capacity and not to the voltage generated, generators for very high voltages but small output can be designed very small. They can operate without supply from the general mains, and can be driven by battery-fed electric motors, by petrol engines, and even manually.

Being thus completely self-contained, they can be

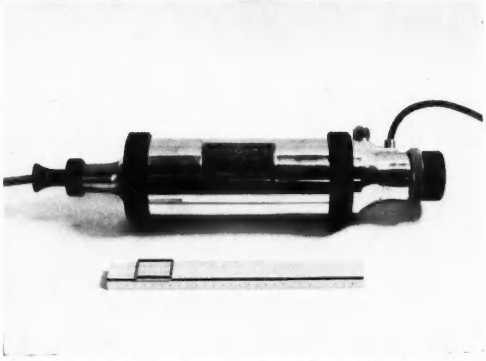

Fig. 1. **Small electrostatic generator for very high voltage.**

used without difficulty on building sites, in workshops, on motor-cars, on the land, or in collieries.

The machines are robust, can be subjected to over-voltages and short-circuits without detriment, and they are not sensitive to atmospheric conditions. They are also cheap to produce and simple to install. They are self-exciting when the input terminals are connected to a sufficiently low resistance, and they generate d.c. direct, so that there is no need for any kind of rectification.

The current intensity and the voltage are changed by changing the speed and the spacing of the discharge points. An increase in voltage or current intensity can also be obtained by connecting a certain number of machines in series or in parallel, a procedure which permits of obtaining voltages of the order of 130,000. There is no condenser which could provide a discharge, and the short-circuit current cannot exceed the full-load current. Their use, therefore, does not present any danger to the operator.

The smallest types of these machines generate a maximum voltage of 70,000 volts with an output of 120 micro-amperes and operate in a vessel filled with a nitrogen-air mixture of 25 atmospheres pressure. The rotor is driven through a shaft, normally by either a direct current or asynchronous motor.

These new industrial electrostatic machines can be used with advantage as a source of electricity for electronic equipment ; they are already being used, for instance, for electron-microscopes, where their easy and instantaneous starting is particularly valuable. They are also in use for medical equipment, and in agriculture

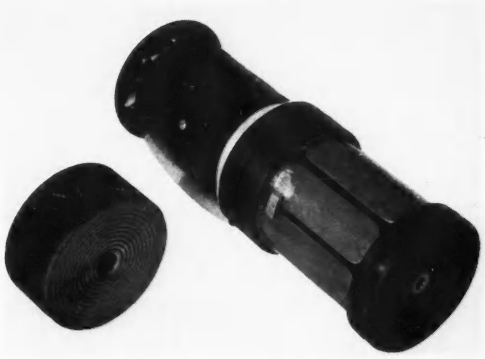

Fig. 2. **Rotor of an electrostatic generator for very high voltage.**

for spraying insecticide powders, which, if this method is used, adhere to the plants to be protected. They can also be used for testing insulation, including transformer oils, and for the operation of vacuum tubes and, in particular, all kinds of discharge tubes.

The uses of direct current of very high voltage have until now been relatively few ; these small industrial machines will no doubt, make it possible to explore a great variety of new fields for high voltage d.c.

U. S. A.

Health Hazards from Cosmic Radiation at High Altitude

By H. J. SCHAEFER. (From *Technical Data Digest*, Vol. 15, No. 10, October 1950, pp. 21-26, 4 illustrations.)

The intensity of cosmic radiation at sea level is extremely small, but it increases rapidly with altitude. The attention of scientists has so far been concentrated on the nuclear reactions caused by cosmic rays, and little work has been done on the biological effects of the different components of radiation. To assess these effects, exact numerical data on the total ionising power and specific ionisation of cosmic rays and their dependence on altitude are required.

BEFORE outlining the numerical data available at present, and the tentative conclusions that may be drawn from them, a simplified summary of present-day knowledge of cosmic radiation will be given.

The primary radiation, the origin of which is not known, appears to consist predominantly of protons, and contains heavier charged particles as well. The energy of these primary particles is enormous, averaging about 20×10 electron-volts. (1 eV = energy of an electron accelerated through 1 volt). There is no evidence for primary particles of energies less than 10^9 eV, but there appears to be no upper limit to their energy : particles with energies of 10^{17} eV have been found.

Even the most powerful particle accelerators of today cannot produce energies greater than 4×10^8 eV, i.e., below the lower limit of the cosmic ray primaries. The study of nuclear processes reveals that reactions produced by particles in the 1000 MeV (million electron-volts) range are very different from reactions in the MeV range. The fundamental difference is that the energy of the 10^9 eV particle is not dissipated in one elementary process, but is distributed to several secondary particles, which carry off enough energy to cause another nuclear disruption, and so on. Thus, a primary cosmic ray particle, on collision with an atomic nucleus in the atmosphere, produces a large number of secondaries. This process is termed shower-production, and must not of course be confused with a chain reaction which is self-sustaining.

Showers are usually classified into two groups : penetrating showers consisting of heavy particles such as protons, neutrons and mesons ; and the soft or cascade-showers of electrons, positrons and gamma rays. These latter may cover an area of several thousand feet across and comprise millions of particles.

All the secondary products of cosmic radiation ionise the air molecules along their path. It is fairly certain that the biological effect of penetrating radiation depends on the ionising power of the radiation, and the Roentgen unit of the biological efficiency of radiation is based on it. The ionising power is measured in terms of specific ionisation, i.e., the number of ion-pairs produced per cm path-length. An important experimental fact is that specific ionisation is low for high velocities, increasing substantially as the particle slows down, and only decreases again shortly before the particle comes to rest. Millikan and his co-workers have measured the total ionisation produced by cosmic ray showers at different altitudes, the relevant results being shown in Fig. 1.

The four curves represent measurements at different latitudes. The vertical scale is based on the value 1·0 for the total ionisation at sea level, while on the right the specific ionisation values of Millikan have been converted into dosage units in milliroentgen. The

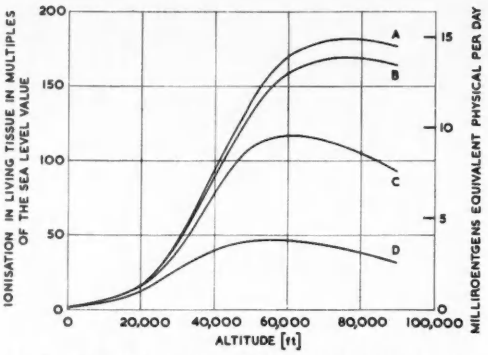

Fig. 1. **Altitude dependence of ionisation in living tissue on cosmic radiation.**

marked effect of the latitude, especially at high altitudes, is explained by the influence of the earth's magnetic field on the charged primaries. At lower altitudes the deflection effects due to the magnetic field are almost completely effaced due to the multiple scattering and resultant direction changes of the shower process.

The biological scale given in Fig. 1, however, is misleading in certain respects. The assumption that the biological effect of radiation is dependent only on the total ionisation produced per gram of living tissue has proved an oversimplification. On comparing the effects of two kinds of radiation differing greatly in their specific ionisation, it was found that equal roentgen doses did not produce equal effects. The most signifi-

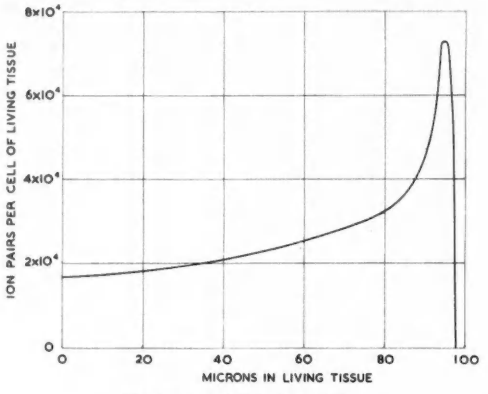

Fig. 2. 9·5 MeV alpha particle.

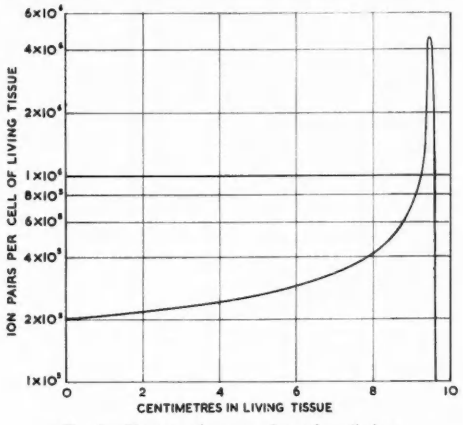

Fig. 3. Heavy nucleus ray of cosmic radiation.

Figs. 2 and 3. **Specific ionisation along particle tracts in living tissue.**

cant difference in this respect exists between alpha and gamma rays : the former are about 10 times as efficient, due to the very non-uniform ion distribution produced in the tissue. These differences must be considered in evaluating the ionisation curves, as there is a continuous change in the kind and velocity of particles as we move from stratosphere to sea level. In other words, the milliroentgen dose rates of Fig. 1 have to be multiplied by a variable factor to obtain the correct biological dose rates. No determination of this variable factor is as yet possible because our knowledge of the distribution of energy to the various components in cosmic radiation is insufficient.

We can, however, make a first approximation in the 0-70,000 ft altitude range. A great number of experimental results in this range show that all cosmic ray particles have a smaller specific ionisation than the alpha particles. The biological effects of alpha radiation have, in turn, been extensively studied, and so, on the basis of a comparative efficiency of 0·5 to 0·8 of cosmic rays, an estimate of the actual biological dose rates can be made. This estimate shows that at 70,000 ft the full tolerance dose is already surpassed. These doses will not cause any somatic damage, but the prospect of an increasing percentage of the population being exposed to such dosages is bad from the genetic viewpoint.

The situation in the region above 70,000 ft is even worse. Recent research with nuclear-emulsion plates in this region has revealed a new component in the primary radiation, the so-called heavy nuclei rays. The specific ionisation of these heavy nuclei can exceed that of alpha particles by a factor far greater than 100, while their penetrating power, due to the high specific ionisation, is small in comparison with the primary protons.

Analysis of the nuclear emulsion plates shows that the particles are the nuclei of heavier elements, stripped of all their orbital electrons, and carry an energy of more than 10^9 eV per nucleon. About 1 per cent of the total radiation is thought to consist of heavy nuclei.

Figs. 2 and 3 show a comparison between an alpha particle from a natural radioactive substance, and a heavy nucleus ray recorded at 90,000 ft. The specific ionisation of the heavy nucleus is so high that no calibration standards exist in this range; Fig. 3 is therefore only an approximation. The alpha track has a length in living tissue of 100 microns i.e., it penetrates about 10 cells. The heavy nucleus has a track length of 9·5 cm, i.e., it penetrates about 10,000 cells.

Accurate measurements on the natural concentration of alpha-active substances in living organisms show that on the average one alpha particle is emitted per minute per gram of organism, and it penetrates an average of five cells. The toxic limit of alpha-activity is about 10 times this value. Calculating the total heavy nucleus dosage at 90,000 ft, it is found that about 15 times as many cells are hit than by alpha rays in natural concentration. But we must also consider the very much higher ionisation produced in each cell by the heavy nucleus, especially towards the end of its track. At this point we have a zone of complete destruction of at least one cell in cross-section for a length of 10 to 50 cells.

There is no danger of human beings above 70,000 ft being killed instantly or within a short time by the heavy nuclei rays, but the harmful effects are slowly accumulating. There is also reason to assume that beyond 90,000 ft the intensity of radiation steadily increases as the stopping power of the atmosphere decreases.

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

ELECTROLYTIC POLISHING

Plastic Deformation of Electrolytically Polished Brass Surfaces.

By F. KRÁLÍK and I. ŽÁDNÝ. (From *Hutnické Listy, Czechoslovakia*, Vol. 5, No. 10, October, 1950, pp. 412-414, 15 illustrations.)

THE authors have investigated the possibility of utilising electrolytically polished surfaces for investigating the process of plastic deformation of brass specimens. Specimens of the α and the $\alpha + \beta$ type were electrolytically polished in 85 per cent H_3PO_4, which was diluted with methylalcohol to a specific gravity of 1·4. A voltage of 5 to 8 V and a current density of 20 to 30 A/dm² was applied. The polishing time was ½ to 40 minutes, according to the state of the surface after preliminary treatment and the composition of the specimens. The size of the specimens was 10 × 7 × 80 mm and one surface of the area 10 × 80 mm was electrolytically polished. The plastic deformation was obtained by applying tensile stress to the specimens in a tensile testing machine. Microphotographs were taken for various stresses and degrees of deformation. These show that the progress of plastic deformation and its influence on the changes of the grain structure can conveniently be studied from the changing appearance of a surface which has been electrolytically polished before the plastic deformation has started. The formation of sliding planes and the displacement of crystallites can be conveniently observed. It is believed that this method will be useful for the investigation of creep phenomena in long-time tests and also for studying the formation of cracks and stress concentrations. Unlike a mechanically polished surface, electrolytically polished surfaces do not show any deformation or heating effect due to the contact of this surface with the polishing tool, and thus represent an ideal cross-section of the material.

IRON AND STEEL

The Revival of the Acid Bessemer Process.

By W. EKMAN. (From *Jernkontorets Annaler, Sweden*, Vol. 134, No. 7, 1950, pp. 301-342, 16 illustrations.)

THE behaviour of nitrogen in the acid Bessemer process is discussed on the basis of investigations and experiments at Swedish steel works. The final nitrogen content is assumed to be a result of two simultaneous, but counteracting, processes. On the one hand, nitrogen is taken up from the blast and, on the other, nitrogen is given off in connection with the gas formation when iron oxidised by the blast is reduced by the carbon in the bath. The resulting nitrogen content depends upon which of these factors predominates. If this hypothesis holds true, the nitrogen content should rise when elements other than carbon are oxidised. This is shown to be the case. Rapid oxidation of silicon is followed by a considerable rise in the nitrogen content, at least towards the end of the blow when the nitrogen solubility is high. Another consequence of the hypothesis is that the absorption of nitrogen should decrease if the blow is conducted in such a way that the steel quantity in direct contact with the blast is lowered. This is in accordance with known facts concerning nitrogen absorption where different blowing methods and converter constructions are involved. A patented method for obtaining a low nitrogen content in the steel by means of ore additions and inclined blowing is described. The possibility of lowering the nitrogen content should considerably increase the applicability of acid Bessemer steel. The new methods of dephosphorising and desulphurising coke pig iron make it possible to use such iron as a raw material for acid Bessemer steel. In Sweden, acid Bessemer steel is a suitable basic material for quality steel production in electric or open hearth furnaces.

LIGHT METALS

On the Cracking of Aluminium-Magnesium Alloys in Contact with Mercury.

By A. JACQUET and A. R. WEILL. (From *Revue de L'Aluminium, France*, Vol. 27, No. 172, December, 1950, pp. 442-451, 22 illustrations.)

THE authors have sought to determine up to what point the mercury salt test, frequently used to establish the tendency of copper alloys towards intergranular cracking, could give useful information in the case of aluminium alloys with a high magnesium content, showing internal stresses and submitted to the action of a saline atmosphere. Their study has been focussed on the case of compressed air cylinders made in aluminium alloys with a 7 per cent magnesium content, used aboard ships and exposed to sea-water corrosion. This alloy composition was selected to afford a maximum of weight saving in a particular case, whereas the alloys normally used for the manufacture of cylinders generally contain less than 6 per cent of magnesium. A few abnormal fractures occurring under service conditions, when several thousands of this type of 7 per cent magnesium cylinder were used, led to an enquiry to determine the causes, and the question has arisen as to whether the mercury salt test would permit of finding a relation between the tendency of this alloy of exceptionally high magnesium content to crack in a saline atmosphere and the structural heterogeneities.

MACHINE SHOP PRACTICE

Cylinder Head Broaching Tools Feature Carbide Inserts

(From *The Iron Age, U.S.A.*, Vol. 166, No. 7, August 17, 1950, pp. 96-97, 3 illustrations.)

CUTTERS with single-point carbide tipped roughing teeth and solid carbide blade-type finishing teeth are now used in broaching machines to broach four sides of grey cast iron cylinder heads. Because of the construction of the cutter, the single-point tools can be removed in a matter of minutes, as against hours required to remove and resharpen a section or more of the conventional broaches. The cylinder head finish is flat and smooth, with no crumbling of the metal around the critical edge of the combustion chamber. The blade cuts through scale or hard spots in castings without nicking or burning.

These special broach cutters were developed to reduce the maintenance and grinding costs incurred with conventional high speed steel broaches and to overcome the trouble caused by hard spots in castings.

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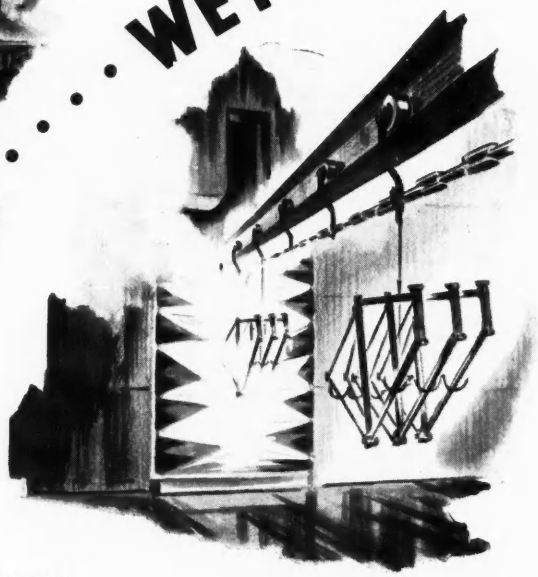

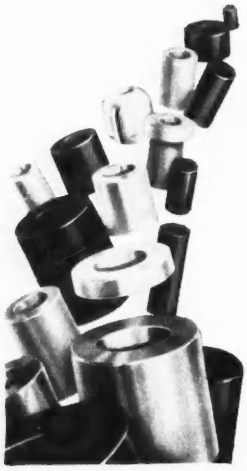

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Machine Shop Practice—*continued.*

There are four branches mounted in opposed pairs on the machine columns of a horizontal, hydraulic, push-broaching machine. Each pair of broaches consists of a main broach for broaching one face of a cylinder head and a rail broach for broaching one side. Thus, in a single back-and-forth sweep of the machine, the top, bottom and two sides of a cylinder head are finished.

Main and rail broaches are similarly constructed. Major differences are that the main broaches are in four sections and rail broaches are in two sections. There is also a slight difference in size of the single point tools used.

To lock the tools into the broach bodies, a screw reached from the surface of the broach is used. This screw tightens against the milled recess in the tool shank. It is not necessary to remove the broach holder to sharpen individual tools. Any worn tools can be replaced with sharp tools, set to the required height by individual adjusting screws.

WELDING

Hard-Facing of Steam Valve Seats and Discs.

By O. E. Swenson. (From *The Welding Journal, U.S.A.*, Vol. 29, No. 12, December, 1950, pp. 1053-1058, 11 illustrations.)

Hard-facing of high-temperature, high-pressure steam valve seats and discs is a generally accepted practice. Engineering and catalogue information does not, however, sufficiently emphasise the importance of selecting low-velocity welding tips for applying the hard overlays. One of the purposes of this paper, in presenting an outline of the general welding procedure and the fundamental differences in heating effects of low, medium and high velocity tips, is to stress the benefits of employing low velocity tips.

It is shown that different overlay compositions, such as chrome-nickel-boron, chrome-cobalt-nickel-molybdenum and cobalt-chrome-tungsten may be interchanged when flame ratios and deposition conditions are controlled.

A descriptive explanation of the methods for evaluating hard-facing alloys and testing devices designed at the U.S. Naval Engineering Experiment Station for determining hot hardness, hot impact values and steam tightness are included to interest both the engineer and the welder.

Terminology in the field for the degree of acetylene flame varies widely. It is suggested that consideration be given to designating a descriptive mathematical ratio of length of acetylene feather to length of inner cone as a qualitative measure of the amount of acetylene flame.

Mash Resistance Welding.

By O. Broner. (From *Materials and Methods, U.S.A.*, Vol. 32, No. 4, October, 1950, p. 77-78, 3 illustrations.)

When mild steel sheets are to be joined end to end without overlap or other protruding metal, they can be welded by either the fusion or resistance welding process. The electrical resistance flash-butt welding system is most often used for such applications, but has the disadvantage of leaving a flash that must be removed by grinding or machining. Mash welding is a relatively new application of resistance welding technique. It makes use of either the seam welder or the projection type welder, and may sometimes be a better solution to this problem.

In conventional seam welding, the sheets are ordinarily overlapped $\frac{3}{4}$ to 1 in., depending upon the thickness of the sheet stock being welded. Any attempt to reduce this overlap may result in sheet deformation and spitting of the weld metal at the faying surfaces. In mash welding, the amount of overlap is limited to approximately $1\frac{1}{2}$ times the sheet thickness, and the welding pressure is increased to approximately twice that required for conventional seam welding, thus forcing the plastic metal from an overlap of two sheets into a single sheet only slightly thickened at the weld joint. Because the weld metal is restrained at both top and bottom by the electrode wheels, there is no ejection of metal and a minimum irregularity in the finished surface at the joint. The joint in the as-welded condition is suitable for many purposes without further grinding or other finishing procedures.

CYBERNETICS—OR THE SCIENCE OF GOVERNING

(*Concluded from page* 6)

analysis may well be applied in future to the study of nervous diseases.

Finally, cybernetics has many useful ideas to contribute to social theory, although far-reaching results cannot be expected in this field, owing to the enormous complexity and essentially non-statistical nature of social processes over historical periods. There may be a mass sociology of human beings, as there is of molecules or even fruit-flies, but it would have to be on such a time-scale as to be irrelevant to the individual, just as the kinetic theory is irrelevant to the individual molecule. Nevertheless, the study of the principles of communication cannot fail to increase our understanding of society, where such processes play an overwhelmingly important part.

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A DOMESTIC HEAT PUMP WATER HEATER

(*Concluded from page* 17)

The operating conditions under which this group of pilot models was tested varied over a wide range, as far as hot water requirements are concerned. The average daily hot water consumption varied from 25 gallons per day in a residence occupied by two persons without automatic hot water consuming appliances, to 88 gallons per day in a residence occupied by eight persons with an automatic dish washer and three baths.

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The dehumidification of the ambient air by the unit was in all cases an effective and desirable characteristic.

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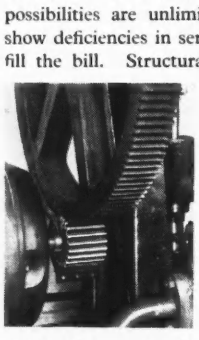

A Tufnol Pinion meshing with a cast-iron wheel. The 18 h.p. motor provides the pump drive for a Hydraulic Accumulator.

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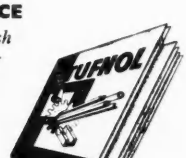

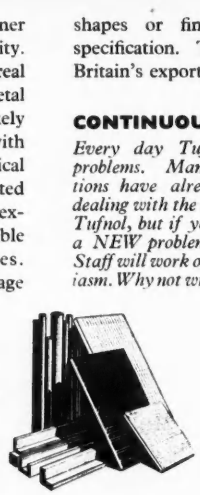

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NEWS OF THE MONTH

PERSONAL.

Mr. B. O. Ashford, F.R.I.C., has been appointed development engineer at the Eastleigh works of Pirelli-General Cable Works Ltd.

Lieut.-Colonel Austin G. Bates, D.S.O., has been elected a director of the Cunard Steam Ship Co. Ltd. and of Cunard White Star Ltd.

Colonel J. G. B. Beazley has been elected chairman, and **Mr. Edmund Gardner,** deputy chairman of the Mersey Docks and Harbour Board.

Mr. W. Fillingham Brown, B.Sc.(Eng.), M.I.C.E., has been elected president of the Institution of Sanitary Engineers, 118 Victoria Street, London, S.W.1.

Mr. R. Buckley, publicity manager for Kolster-Brandes Ltd., and Kent Mouldings Ltd., has now been also appointed as publicity manager for Brimar Valves and of the Industrial Supplies Division of Standard Telephones and Cables Ltd.

Mr. R. N. Cadbury, B.A., has been appointed sales director of E.M.B. Company Ltd., Moor Street, West Bromwich.

Mr. V. J. Chalwin, managing director of J. & H. McLaren Ltd., Leeds, has been appointed managing director of Petters Ltd., chairman of Bryce Fuel Injections Ltd., and a director of Berger Equipments Ltd.

Mr. R. L. Chantrill, B.Sc., M.I.E.E., A.I.E.E., chief technical engineer of The British Thomson-Houston Export Co. Ltd., has been elected a director of the Company.

Mr. J. K. Clark, B.Eng., A.M.I.E.E., A.M.I.Mech.E., has been appointed chief engineer of the Electro Chemical Engineering Co. Ltd., Netherby, Weybridge, Surrey.

Mr. G. F. Cole has been appointed general manager, and **Mr. E. S. Pearson,** secretary, of Clarkson (Engineers) Ltd., Nuneaton.

Mr. C. H. Dolphin has retired from the office of publicity manager of the English Steel Corporation Ltd. and Darlington Forge Ltd., after 43 years' association with the steel industry.

Sir Archibald Forbes has been elected deputy-president of the Federation of British Industries.

Mr. J. H. Gibson, A.M.I.Mech.E., chief engineer of Dewrance & Co. Ltd., has been appointed a director of the company.

Mr. E. A. Gough has been appointed advertising and publicity manager of High Duty Alloys Ltd., Slough.

Mr. W. T. Hill, commercial manager of the Osborn Foundry & Engineering Co. Ltd., Sheffield, has been appointed a director of the Company.

Mr. Harold Hobson has been elected to the Board of Directors of the General Electric Co. Ltd.

Captain W. H. Hunt has been appointed marine superintendent of the Blue Star Line Ltd., 15 W. Smithfield, London, E.C.1.

Mr. A. K. Jordan has been appointed assistant general sales manager of Northern Aluminium Co. Ltd., Banbury.

Mr. G. W. Lacey has been appointed director in charge of sales of The British Aluminium Co. Ltd., Salisbury House, London Wall, London, E.C.2. **Mr. R. G. H. Linzee** has been appointed director in charge of establishment; **Mr. G. A. Anderson,** general sales manager and **Mr. H. H. Cundell,** home sales manager.

Mr. Felix L. Levy, a director of the " 600 " Group of Companies has been elected chairman and managing director of the New London Electron Works Ltd., London, E.6. **Mr. W. Clarke** has been elected to the Board.

Mr. Reginald J. Lewis has been appointed a director of Kerry's (Gt. Britain) Ltd., Stratford, London, E.15.

Mr. L. McEwan has been appointed naval architect to the Cunard Steam Ship Co. Ltd.

Mr. F. C. McLean, M.I.E.E., has been appointed Head of the newly formed engineering projects group of the British Broadcasting Corporation. **Mr. E. L. E. Pawley, M.I.E.E.,** has been appointed Head of the engineering services group, and **Mr. A. N. Thomas, A.M.I.E.E.,** Head of the planning and installation department.

Mr. W. J. Morgan, M.I.Mech.E., has been appointed general manager, and **Mr. H. W. Finn,** secretary of The Machine Tool Trades Association.

Mr. E. Pasley, chief metallurgist, and **Mr. H. Dakin,** forge master, have been appointed to the Board of the Titanic Steel Co. Ltd., Sheffield.

Mr. Vaughan Pendred has joined Head, Wrightson & Co. Ltd., to take charge of the company's sales organization.

Mr. J. Barclay Peat, M.I.C.E., has retired from his office of managing director and has been appointed deputy chairman of the Tees Side Bridge and Engineering Works Ltd., Middlesbrough, **Mr. Wilfred L. Fletcher, A.M.I.C.E.,** has been appointed managing director.

Mr. C. N. Sherwood has been appointed Head of the Public Relations Department of the Metals Division of Imperial Chemical Industries Ltd., in succession to **Mr. H. O. Smaldon.**

Mr. John Simpson, manager of the machine tool department of George Cohen, Sons & Co. Ltd., has been elected a director of the Selson Machine Tool Co. Ltd.

Mr. T. A. Simpson has been appointed deputy general manager of the Marconi International Marine Communication Co. Ltd., Marconi House, Strand, London, W.C.2.

Sir Thomas G. Spencer, M.I.E.E., managing director of Standard Telephones and Cables Ltd., Connaught House, Aldwych, London, W.C.2., has been elected chairman of the Board of Directors. He succeeds the late Sir Frank Gill, K.C.M.G., O.B.E., who died on October 25th, 1950.

Dr. Charles Sykes, F.R.S., has assumed the position of deputy managing director of Thos. Firth & John Brown Ltd. **Mr. Eric Mensforth, M.B.E.,** has assumed the position of managing director of Firth Brown Tools Ltd. **Mr. T. H. Burleigh** has been appointed sales director.

Mr. B. Chetwynd Talbot, managing director of the South Durham Steel and Iron Co. Ltd., has been elected chairman of the Company.

Mr. Frank Tinker has been appointed Northern area manager of Birlec Ltd., Birmingham, with headquarters at Surrey House, Arundel Street, Sheffield 1.

Mr. J. B. Thomas, F.C.A., deputy chairman and managing director of Hadfields Ltd., East Hecla Works, Sheffield, in consequence of his retirement is relinquishing these appointments at the end of the present month and will be succeeded by **Mr. Harold Humphries,** deputy managing director of the company.

Dr. O. H. Wansbrough-Jones, C.B., O.B.E., has been appointed Principal Director of Scientific Research (Defence) at the Ministry of Supply.

Mr. H. T. Wordsworth, commercial director of Sanderson Brothers & Newbould Ltd., has been appointed general manager of the Company. **Mr. J. R. A. Bull,** formerly general manager of Sanderson-Newbould (S.A.) Pty. Ltd., Johannesburg, has been appointed sales manager and member of the Board. **Mr. E. O. Stubbings** has assumed the position of London Director of the Company.

Sir Eric Young, M.I.Min.E., M.I.C.E., F.G.S., who has resigned his office as a production member of the National Coal Board, has resumed his seat on the board of directors of the Bolsover Colliery Co. Ltd., Bolsover, Chesterfield.

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JAMES WATT INTERNATIONAL MEDAL AWARDED TO DISTINGUISHED DANISH ENGINEER

The Council of the Institution of Mechanical Engineers have awarded the 1951 James Watt International Medal to Dr. H. H. Blache, of Denmark, for his contributions to the advancement of mechanical engineering, and particularly for his pioneer work in the development of the large Marine Diesel Engine.

Dr. Blache was nominated by the Danish Society of Engineers.

The James Watt International Medal was founded to commemorate the bi-centenary of the birth of James Watt, on 19th January, 1736. Previous awards of the James Watt Medal have been made to :—

1937 Sir John A. F. Aspinall (Britain) for his work on the development of the railway locomotive and services to mechanical engineering generally.

1939 Henry Ford (U.S.A.) for novelty and great variety in the machines he designed and his special methods of continuous mass production especially of motor cars.

1941 Professor Aurel Stodola (Switzerland) for his work on the thermodynamics of the steam turbine.

1943 A. G. M. Michell (Australia) for researches in lubrication leading to his invention and development of the modern thrust block.

1945 Dr. F. W. Lanchester (Britain) for his pioneer work in automobile engineering and in aeronautical science.

1947 Professor Stepan Timoshenko (U.S.A.) for his contributions to engineering science as a teacher and particularly for his work on elasticity.

1949 Dr. Fredrik Ljungström (Sweden) for mechanical enginering developments, the most notable of which is the air preheater which bears his name and the steam turbine, developed jointly with his brother, the late Birger Ljungström.

FIRST EUROPEAN MACHINE TOOL EXHIBITION

The First European Machine Tool Exhibition, organized by the European Committee of the Machine Tool Industries, will be held in Paris from 1st to 10th September, 1951. The Exhibition will show an exceptional range of machine tools and allied equipment and meterials, as next to European manufacturers, American and Canadian builders of machine tools and equipment will be included.

Further information can be obtained from M.B. Gardair, First European Machine Tool Exhibition, 2 bis Rue de la Baume, Paris (8e), France.

WORLD METALLURGICAL CONGRESS

The American Society for Metals has appointed Dr. Zay Jeffries, world renowned author and scientist, a former President of the American Society for Metals, Director General of the World Metallurgical Congress to be held at Detroit, Michigan, from October 15 to 19, 1951, simultaneously with the 33rd Annual National Metal Congress and National Metal Exposition.

The Congress and Exposition will provide an opportunity for conference at the highest level and for exchange of ideas among leading metal technologists and scientists, particularly from the ferrous and non-ferrous metal-producing and fabricating countries as well as among representatives of metallurgical companies and organizations.

The purpose of the Congress is 1. To share scientific knowledge and technical and business "know-how" by planned plant inspections and informal discussions ; 2. To cement friendship and goodwill by social gatherings in various American cities ; 3. To interchange technical and scientific knowledge to help raise the standard of living of the world ; 4. Week-long meetings at top scientific levels in the metals industry at the National Metal Exposition and Congress ; 5. To confer, discuss and exchange latest information and knowledge in respective fields of the metal industry ; 6. To counsel and discuss conversation, utilization and substitution for strategic metal.

FESTIVAL OF BRITAIN 1951 VISITS TO FACTORIES

British manufacturers who are willing to receive visitors at their factories during the Festival of Britain, 1951, are invited to send particulars to the Council of Industrial Design. The Council will compile a list of such firms and arrange for it to be carried at all Industrial Information Bureaux in the official Festival Exhibitions. The list will be issued to visitors on presenting a trade business card.

For two years the Council of Industrial Design, as a constituent body of the Festival Organisation, has appealed through the trade associations and in many meetings and conversations with industrialists for the opening of British factories to visitors. Interest in the project is now growing, at home and overseas, and the Council seeks to record in advance of the opening date details of those firms which are prepared (and not debarred for security reasons) to make this important contribution to the Festival. The Council cannot, of course, guarantee that every firm on the list will be visited.

Manufacturers who would like their names to appear on the list should write to Mr. S. D. Cooke, Council of Industrial Design, Tilbury House, Petty France, S.W.1., enclosing in addition to the name and address of their factory some particulars of the goods they make, the approximate number of employees in the factory or other indication of size, the most convenient days and hours for receiving visitors and the person to whom visitors should apply in advance. Details of languages spoken by staff available as conductors will be welcome.

CHANGE WHEEL GEARING

REPRINT NOW AVAILABLE

Reprints of the article "Change Wheel Gearing," by O. Lichtwitz, M.I.Mech.E., are now available. Originally published in this journal in six instalments from January to June, 1950, the article has met with considerable interest among our readers. We have, therefore, decided to reprint it as a ready-reference work for all those concerned with change wheel gearing problems.

New readers of this journal may be interested to know that the treatise deals with various problems encountered in change gears. Some mathematical fundamentals required for their computation are condensed in a preparatory chapter, thus avoiding any break of sequence in the following sections, which deal with the computation proper. The method developed in these sections makes it possible to find gear trains with any specified accuracy, or to find the best solution obtainable with a given set of change wheels. It has frequently been found, after a gear train has been calculated, that it could not be mounted. The author demonstrates how a proper arrangement of the gears can readily be obtained without resorting to trial-and-error methods, and how such an arrangement, at the same time, ensures the least possible tooth loading.

Indexing when cutting multiple threads in a lathe introduces additional demands on the gear arrangement, and these problems are also dealt with.

The concluding chapter is devoted to the gearing of machine tools and contains ready-for-use tables for screw cutting, including metric and worm threads, which are often found to be troublesome.

An abridged factor table, which, however, meets the most exacting requirements, makes this booklet self-contained. A great number of examples from practice are worked out, and these should prove to be useful as a guide.

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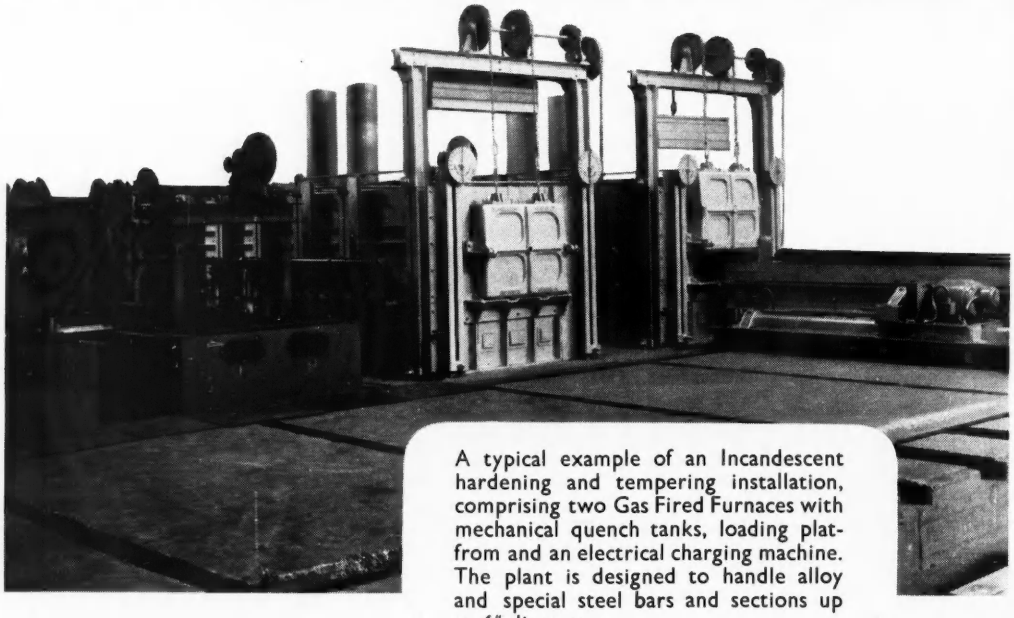

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AIRLINERS OF FUTURE SHAPED LIKE FIGHTERS

Jet airliners shaped like big swept-wing fighters are forecast by leading British designers. G. Edwards, designer of the Vickers *Viscount*, thinks these pure jet airliners will have thin swept-back wings, with engines either buried in them or carried beneath the wing in nacelles. In the tropics pure jets will probably need rocket to assist their take-off. The propeller-turbine types, on the other hand, will probably look much as they do today. Their wings will not need to be swept-back to any appreciable extent. For the next 12 years they will probably cruise at between 300 and 400 miles-an-hour and will, Edwards says, be used mainly on the medium and short stages.

Edwards thinks civil aircraft speeds are unlikely to exceed 550 miles-an-hour for perhaps the next 20 years. At 40,000 ft., this is getting near the speed of sound. Engine designers' efforts for economy in fuel consumption will be a big factor.

Major Halford, designer of the *Ghost* gas-turbine, power unit of the *Comet*, foresees better fuel economy from higher compression-ratios with axial-types of engines, propellers running in ducts and supersonic airscrews. Present-day airline centrifugal turbines have a fuel consumption something like two-and-a-half times that of a comparable piston-engine but their high speed more than counter-balances the extra cost of fuel because they make more trips in a given time. To raise the compression ratio of compressors, designers have already begun experiments into the possibility of passing air over compressor blades at supersonic speeds. If these experiments succeed, said Major Halford, they will simplify compressors and reduce weight.

He has also given some indication of the power of the present-day jet airliner. The *Comet*, which will probably have an operational life of 15 years, has the power to cut existing airline time-tables by half. Piston-engines designed to give the same power output as the four *Ghost* engines weigh on their own as much as the complete *Comet*.

Both Halford and Edwards described the effect of these designs on the airline passengers. Pressurised cabins will be essential: the passenger will fly in great comfort, and fly more cheaply because of reduced maintenance costs. Most important of all, he will be much safer. Kerosene is a safer fuel and Edwards thinks that the twin-engined aeroplane might become virtually obsolete since four of the light-weight turbines could be installed in aeroplanes which nowadays carry only two piston-engines. The inherent safety of a four-engined aeroplane will also, therefore, be with the passenger.

Major Halford has described the "unique experience" which will soon be the common lot of everyday passengers in a jet airliner. "At 40,000 ft. there is a strange sensation of being poised motionless in space because at that height the ground below scarcely appears to move and the aircraft remains rock steady in the stable air. The lack of vibration and the absence of all sign of an engine, propeller or any moving part makes this illusion complete. On the other hand one arrives at a far distant landmark in an incredibly short space of time but without any sense of having travelled. If the weather is clear one has unbelievably fine views. From a position of 40,000 ft. over the English Channel I have seen the whole of the south-east of England from Start Point to the Wash on one side and on the other the coast of France from Cap Griz Nez to the Seine estuary. At the height at which the Comet flies the air is very thin and intensely cold but the air conditioning system maintains a comfortable pressure and temperature so that no discomfort is felt by the passenger."

JET ENGINE TEST CELLS SILENCED BY UNIQUE USE OF INSULATING FIREBRICK

The unique application of an insulating firebrick to muffle the roar in jet engine test cells has been made public by The Babcock & Wilcox Company. The firebrick is being used in exhaust stacks at the Lockland, Ohio, plant of the General Electric Company where engines for J-47 turbo jets are manufactured. A total of 14 test cells have been treated with the B & W Insulating Firebrick.

Noise made by exhaust gases from the engines, forced out of the stacks at a velocity of 275 to 340 miles an hour, without sound treatment would be extremely objectionable. With the insulating firebrick used acoustically, the sound is so reduced that at a point a short distance from the plant it is no louder than a noisy office.

The brick, known as B & W K 26 Insulating Firebrick, is normally employed for high temperature insulation for lining industrial furnaces. Several years ago, tests on this insulating firebrick showed that it had unusual sound absorbing properties as well as resistance to high temperature.

The plant at Lockland had been used for the manufacture of propeller type airplane engines by the Wright Aeronautical Corporation during World War II and was acquired from the government by General Electric. Cells for testing this type of engine were an integral part of the building, constructed with reinforced concrete walls. Although the space allowance was smaller than is usually required for jet engine testing, the original cells were utilized successfully with the insulating firebrick used as acoustical material. Ordinarily, the larger the area acoustically treated, the more efficient is the sound reduction.

The test cells are chambers approximately 80 feet long and 20 feet wide. From a side view they appear U-shaped, with a 20-feet ceiling rising to 45 feet at each end. Air for combustion of the fuel is admitted through one of these ends, passes through and around the motor placed for testing in the chamber, and is ejected along with exhaust gases from the engine, through a steel pipe which runs part of the length of the cell and makes a right angle bend to go up 20 feet into the exhaust stack.

The exhaust stack is 50 feet high with an inside diameter of six and one half feet. It is lined with the specially treated B & W K 26 Insulating Firebrick four and one half inches thick. Exhaust gases passing through the stack may have a temperature as high as 900° Fahrenheit. Most sound absorption material will not withstand this degree of heat.

The considerable lessening of noise indicated by sound level recordings taken at the stacks and at various distances from the plant, is due in great measure to the reduction of a wide range of sounds which commonly are hard to suppress. The insulating firebrick used in the stacks is unique in that it absorbs sound efficiently over a wide range of frequencies. Many acoustical materials are capable only of selective absorption. That is, they may absorb high frequency noises and have very poor absorption characteristics for low frequency sounds, or the reverse may be true.

After more than two years' service the stack linings of all the cells were reported still in excellent condition.

BUSINESS NOTES.

Brush Bagnall Traction Ltd., with executive offices at The Falcon Works, Loughborough, has been formed as a new company to handle the diesel-electric and electric traction business of the combined Brush Group. The Hon. A. C. Geddes is managing director and Mr. P. J. Martin, sales manager of the company.

Standard Telephones and Cables Ltd. have formed a heat treatment group as a part of their Industrial Supplies Division, located at Footscray, Kent. Manufacturers are invited to send their problems for investigation, the result of which will be embodied in a report, with recommendations as to method, type of equipment and approximate price.

The Lapointe Machine Tool Co. Ltd., announce that their offices have now been transferred to the new premises at Otterspool, Watford By-Pass, Watford, Herts. Telephone: Gadebrook 3711-2.

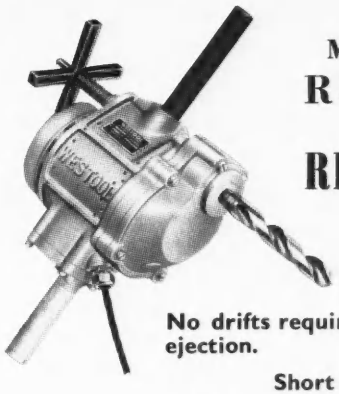
Machine Shop Equipment Ltd., 14-28 Spenser Street, London, S.W.1., have been appointed exclusive distributors for Great Britain of the following German machine tool manufacturers and distributors:—Hahn & Kolb, Stuttgart; Raboma, Berlin; Gustav Wagner, Reutlingen; Droop & Rein, Bielefeld; Stieber Rollkupplung, Munich; Bauer & Schaurte, (for thread grinding machines only), Solingen; and Hommelwerke (universal machine tool, mobile unit, only), Cologne.

The Industrial Department of **Philips Electrical Ltd.,** Birmingham, is now accommodated in the main branch premises at 28a and c, Ludgate Hill, Birmingham.

Charles Churchill & Co. Ltd., South Yardley, Birmingham, have been appointed sole agents for two British lathe manufacturers, namely Timbrell & Wright Ltd. and Anderson (N.M.) Ltd.

Edgar Allen & Co. Limited have secured an order for approximately 1,200 tons of manganese steel castings for lining ball and rod mills at a large copper mine in Chile. As the order originated in New York, some 260,000 U.S. dollars are involved in the transaction. It is intended that a portion of the castings shall be made in the steel foundry of Edgar Allen's subsidiary company in France.

ELECTRIC DRILLS



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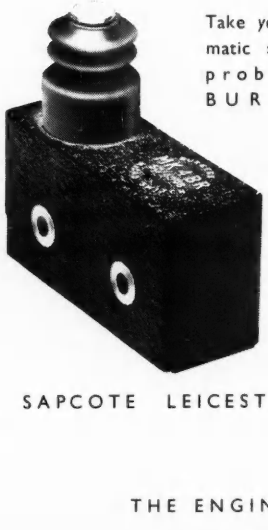

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Acru Finger Tools. The Acru Electric Tool Manufacturing Co. Ltd., 123 Hyde Road, Ardwick, Manchester 12, have just commenced the manufacture of finger tools designed to speed up assembly production. Four of these finger tools, available as box tools to hold nuts in position, screwdriver ends, and tweezers, can be fixed on the hand, without interfering with normal work.

Brush Export Ltd., has opened its London office in Duke's Court, Duke Street, St. James's, London, S.W.1., headquarters of the Brush/ABOE Group of Companies. Mr. C. W. Glanister, M.I.E.E. has been appointed London Manager.

B.S.A. Tools Ltd., Mackadown Lane, Marston Green, Birmingham, has appointed the Rudel Machinery Co., of New York, agents for all B.S.A. machine tools and Index single-spindle automatic screw machines in the North-Eastern states of the U.S.A.

Data Sheets for Engineering Students and Apprentices. A set of data sheets, supplied in an attractive binder, will form a very useful compendium of Engineers' Precision Tools, into which the student can include his own notes on his engineering studies. Price of the complete set of these drawings is 4/6, including binder. The binder separately costs 1/6, or the sheets separately 3d each. Obtainable from Moore & Wright (Sheffield) Ltd., 14-28, Norton Lane, Meadowhead, Sheffield 8.

Dormer Works Extensions. A £30,000 three storey extension to the works of The Sheffield Twist Drill and Steel Co. Ltd. was opened recently by Mrs. Laure Dormer, widow of the late Mr. H. A. Dormer, first chairman of the Company. The extension which incorporates more production bays equipped with the most modern plant, will result in increased production of Dormer high speed steel twist drills and engineers' small tools.

The Glacier Metal Co. Ltd., Alperton, Wembley, Middlesex, is building a new factory of nearly 25,000 sq. ft. floor space which is needed to relieve congestion and to increase output. This addition, together with the expansion of Glacier's factory at Kilmarnock, Scotland, will provide the Company with a floor area of approximately 415,000 sq. ft.

"Valjoh" Automatic Self-Feed Dowel and End-Forming Machine. Mr. Sidney Lipert, A.F.A.R.P.I., A.Inst.P.I., announces that arrangements have now been completed with E. C. Burrell & Sons Ltd., Victoria Works, Southtown, Great Yarmouth, for the manufacture of these machines in licence. F. J. Edwards Ltd., 359/361 Euston Road, London, N.W.1., retain their appointment of sole distributors for the home and overseas markets. Deliveries will commence in February at the rate of 30-40 machines per month.

A. C. Wickman Ltd., Tile Hill, Coventry, has assumed the sole agency for Usines Tornos, Switzerland, leading manufacturers of Sliding Head Precision Automatics including a range with capacities from $^{5}/_{32}$" diameter to $1^{3}/_{16}$" diameter. Catalogues describing the range of Tornos Automatics will be supplied on request.

BRITISH STANDARDS

(*Copies of British Standards may be obtained from the British Standards Institution, 24, Victoria Street, London, S.W.1.*)

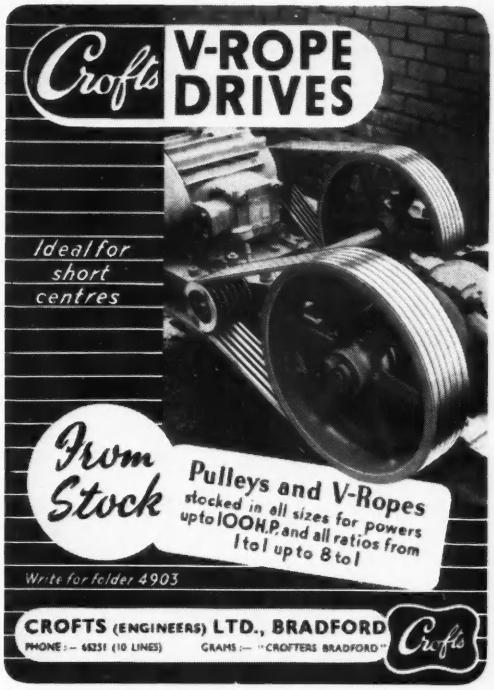
Graphical symbols for instrumentation (B.S. 1646 : 1950). The system of instrument symbols described in this document provides a means of graphical representation suitable for use in any engineering or process-line diagram. It is also suitable for use in engineering and industrial reports and in plant arrangement and layout drawings. The symbols are not primarily intended for use in electrical wiring diagrams, nor are they intended to detail any particular type of instrument or control.

The system has been devised in simple form to enable any combination of instruments or control equipment to be shown in relation to the units of the plant with which they are associated. It is designed to be flexible so that alterations of instrumentation at successive stages of design may be readily shown on a line diagram in such detail as the system permits. Three diagrams are included only to illustrate the application of this system of symbols. PRICE : 2/6.

Guards for couplings and associated shafting (B.S. 1649 : 1950). Prepared with the co-operation of the Engineering Branch of the Factory Department of the Ministry of Labour and National Service, general requirements have been laid down for guards which should be applied to couplings between units such as a motor and a pump, and also guards that are required for a length of shafting and coupling.

Attention is drawn in the foreword to certain features of the regulations dealing with the provision of safety requirements. The specification itself lays down the necessary requirements to ensure that a guard will have sufficient strength and be suitable for its purpose. In addition, one appendix shows different forms of guards and a second appendix gives recommendations for the responsibility of provision of guards. Care has been taken not to define the guards in detail, thus avoiding restriction in design. PRICE : 2/-.

Long-period high-sensitivity tensile creep testing, Medium-sensitivity tensile creep testing Determination of time to rupture under stress with or without measurement of creep strain. (B.S. 1686, 1687, 1688 : 1950). The increasing use of metals at high temperatures during recent years has rendered it essential that satisfactory information should be available about the behaviour of metals at these temperatures. This automatically has given rise to a considerable increase in creep testing, and has in its turn shown the need for standard methods and equipment in order that proper comparisons may be made and correct interpretations given to the tests made by different authorities. PRICE : 2/- each.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LATEST INDUSTRIAL LITERATURE

1. New Metal Cutting Oil Base. Booklet introducing the Antisep cutting oil base which is miscible with water and can be applied to almost every type of machining, including safe and efficient operation on Automatics. Due to the high refrigerating properties of this base, machines can be operated at greater feeds and speeds, yet the work remains cool. Finer finish and improved tool life are further advantages.

2. Sabenite Hard Metal Tips and Tools. 56-page catalogue, profoundly illustrated with diagrams and excellent photographic illustrations, deals with the range of Sabenite hard metal alloy manufactured from tungsten and other carbides, bonded with cobalt. The three main fields of application are given as : tools for cutting ferrous, non-ferrous and non-metallic materials ; dies for the cold drawing of steel and non-ferrous metals ; wear-resistant surfaces and points of contacts in components of engineering plant. Whilst the catalogue deals with cutting tools, it offers some indication of the ways in which Sabenite has been used to solve problems involving wear-resistance. The catalogue includes information on grades ; cutting angles ; shank material ; negative rake ; operating conditions ; brazing ; grinding ; causes of premature failure ; ordering instructions ; recommended speeds and feeds, and a new list of standard tools.

3. Twist Drills and Combined Drills and Countersinks. Cleverly designed and well produced 150-page booklet which should prove to be of great usefulness to all concerned with efficient drilling operations. The contents include excellent Nomenclature and Definitions of the Twist Drill and Combined Drill and Countersink Nomenclature and Definitions, both illustrated diagrammatically and a most useful Twist Drill Service Chart. Sections on the possible causes and remedies of drill failures, on drills of special design for specific purposes, drill speeds and feeds, deep hole drilling, etc., make this booklet of the greatest value.

4. Pumps and Compressors. 24-page booklet, well illustrated, contains specifications of a wide range of hydraulic test pumps both hand- and power-operated types. Descriptions of special pumps for abrasive and glutionous liquids, air compressors and vacuum pumps are also included in the booklet.

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6. Neon Indicator Lamps. Leaflet with illustrated description of a new range of neon indicator lamps for use on machine tools, scientific instruments, switch and fuse boards, transformers, and numerous other types of machinery, instruments, etc. Vast new field of applications is opened for these indicator lamps which can be used directly on the mains voltage up to 440 volts, can be inserted with the greatest ease, are shock-proof and have an average life of 25,000 hours.

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8. Metalclad Switchgear for Industrial Service. Illustrated 8-page brochure deals with a range of metal-clad switchgear, vertical, draw-out pattern, with ratings from 1200 to 3000 amperes for working pressures up to 600 volts. This range has been designed for industries such as iron and steel, paper making, cement and chemical works, where there are many low voltage heavy current circuits to be controlled. Constructional features are described and neatly illustrated.

9. Cutting Oils. This well edited and very neatly produced 54-page booklet should be of great interest and practical benefit to all interested in increasing speed of production, reduction of tool, labour and power costs in all types of machining operations. It offers engineers a brief but valuable survey of improvements in cutting oils and their use.

10. Ceramic Tipped Tools. Illustrated 4-page leaflet announcing and describing Turning and Boring Tools and Milling Cutters with a recently developed ceramic tip. These tools have been proved ideal for machining materials which, though not requiring high forces to remove chips, nevertheless are extremely abrasive and are likely to cause early tool failure. These materials include plastics, particularly those filled with wood, fibre or minerals, and also substances such as graphite and asbestos. Advantages claimed for these new tools include high abrasion resistance ; slow, steady wear characteristic ; anti-weld properties ; low coefficient of friction ; extreme hardness and heat resistance.

11. Steel Selection, Treatment and Design. Unusually well designed 70-page booklet offering guidance to the efficient selection, treatment and application of alloy steels. The booklet contains much metallurgical information of interest. The importance of good design in modern machinery is emphasised in the section devoted to Design. This section contains numerous examples of how to eliminate material in low stress regions and to relieve local stress concentrations.

12. Enlarged Bush Catalogue. Illustrated 54-page catalogue contains full details of a greatly increased range of Bushes, Shackle Pins, Mountings and Couplings. The catalogue is as comprehensive and instructive as possible and it contains a wealth of information, including tables, charts, etc., which will be of value to designers of motor vehicles and others concerned with the control of vibration.

13. Mechanical Tests and their Bearing on Working Properties. 36-page booklet, profoundly illustrated, describes in simple terms the usual methods of testing and the equipment used. It is intended primarily for students and should form an introduction to any further reading. The chapter dealing with the relationship between the mechanical properties and working characteristics of aluminium and its alloys will be of interest to those engaged in forming and finishing these materials. These notes, indicating the nature of the stresses involved in such operations as deep drawing, pressing, spinning, bending and flanging, cold forging, punching and machining, and the mechanical properties required to meet them, may well prove to be the most useful part of the booklet.

14. Handbook on the Maintenance and Preservation of Belting. 10-page booklet intended for users of conveyors and conveyor belting. It includes a number of simple rules which should help in keeping wear and tear on the belt to a minimum.

15. Marine Oil Burners. Illustrated folder depicting a range of oil burners suitable for all makes of water tube boilers, and independently fired superheaters. The folder also contains brief details of a burner designed for use on Scotch boilers and a 2,500 lb/hr. Duplex pumping and heating set.

16. Battery Chargers for Electric Vehicle Service. Neatly produced 8-page leaflet illustrating and describing a range of battery chargers, specially designed and widely used for electric vehicles in factories, coalmines, dockyards and distribution depots. These battery chargers operate completely unattended, variation in current during normal charging being entirely automatic. Details of special designs are included in the leaflet.

17. Timken Tapered Roller Bearings in Automotive Applications. 24-page illustrated Manual offers concise and essential information concerning the care and maintenance of Timken bearings in the Automotive industry. Numerous good diagrams enhance the value of the information relating to the fitting, adjustment and lubrication of Timken bearings.

18. Electrical Measuring Instruments. 24-page brochure depicting a range of electrical measuring instruments, including moving coil instruments, moving iron instruments, voltmeters and ammeters, laboratory instruments, universal test meters and test sets. Specifications and illustrated description of a three range pyrometer is also included.

19. Maxam Air Control Valves. Applications of air equipment extend practically over the whole field of manufacture, and this 44-page booklet is of the widest possible interest. It contains much useful information, including description, specification, illustrations, etc., on air equipment of a high degree of flexibility and wide scope for improving the efficiency of practically any process or operation.

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